Chapter 6
Planning and Conducting Control and Topographic Surveys

6-1. Purpose

This chapter provides general guidance on planning control and topographic surveys. Requirements and methods for extending nationwide control networks into a facility project site are described. Sources of geodetic control data are described. Guidance is also provided on selecting map scales, feature location tolerances, and contour intervals for typical engineering and construction projects. Actual procedural examples of projects performed by various Districts are found in the appendices to this manual.

6-2. Project Requirements from Using Agency

Topographic survey requests originate from the using agency. The requestor might be an internal District office division, an outside Army installation, or another Federal or State agency. Often these requests are general in nature, and often accompanied with a request for a cost estimate to perform the survey. In many cases, the survey details, site conditions, scope, and accuracy requirements are not specified; or, more often than not, the actual work required far exceeds the given budgeted amount. Often, in such cases, the surveyor must meet with the requesting District element or outside agency and modify the accuracy and scope in order to stay within budget. Such budgetary driven compromises do not always result in an optimum survey in the user's estimation; however, the burden is often placed on the surveyor to design a survey accuracy and density that will best satisfy the design/construction requirements that the requesting entity desires. It is rare that the requesting user ever obtains the detail required for the project. Likewise, it is equally rare that the surveyor is able to perform the quality of survey he feels is necessary to adequately define the project conditions. In many cases, an advance site visit may be needed in order to assess the actual conditions and provide a reliable budget estimate (time and cost) to the requesting agency.

Figure 6-1. An advance site visit would be essential in planning for conditions such as this (Portland District)

a. Sample topographic survey request. The following excerpt is taken from a site plan mapping Scope of Work in Pittsburgh District, for a survey of a tract of land adjacent to Hannibal Lock and Dam on the Ohio River. The purpose of the survey was to develop site plans for construction of new facilities on a parcel adjacent to the Hannibal Lock. The originating agency's request may not have been as detailed as this version sent to an AE contractor--it may have only requested a topographic site plan survey without any detailed map scale, accuracy, or utility requirements.

General Surveying and Mapping Requirements.

(1) General site plan feature and topographic detail mapping compiled at a target scale of 1"= 50 ft, 1 ft contour interval for that area annotated on furnished exhibit. Collect all existing pertinent features, drainage characteristics, drainage structures, channels, inlets and outlets, etc. Collect all surface utility data and conduct a thorough search for evidence of subsurface utilities. An underground gas line runs through a portion of the site. Gas line markers are visible.

(2) Set control monumentation as required to adequately control construction layout. Monumentation shall be set in an area outside the construction limits so as not to be disturbed during construction phases. Existing control monumentation within the vicinity may be used in lieu of setting new monumentation. All control monumentation, set or found, shall be adequately described and referenced in a standard fieldbook.

(3) Based on information established by record and by field survey, establish and delineate on the ground, with capped re-bars and witness posts, that portion of the Ohio DOT right-of-way bounding Tract 113; commencing at the edge of the right bank of the Ohio River, thence continuing along Tract 113 and Ohio Route 7. This is a critical element that will need to be properly delineated on the ground and properly annotated on the map to ensure the site is contained within COE property. At a minimum, this portion of the field work shall be performed under the on-site direction of a Professional Land Surveyor duly registered in the State of Ohio.

The above scope effectively describes the requirements of the survey. It does not specify all survey details that could be listed. For instance, it does not state what topographic elevation density is required on ground shot points. These types of details are usually left to the field surveyor to develop--presuming he knows the purpose of the site plan mapping project and is familiar with subsequent design and construction requirements. It is therefore critical that the field survey crew be made knowledgeable of the ultimate purpose of a project so that they can locate critical features which may impact on future construction.

b. Checklist format. An alternate method of describing the survey requirements is a checklist form. The following checklist in Figure 6-2 below is used by FEMA and notes critical requirements that a user/requestor must specify.

Surface Description (choose one)
- ☐ Bare-earth surface (FEMA default)
- ☐ Top surface (e.g., treetops/rooftops)
- ☐ Bathymetric surface

Reflective surface (if using LIDAR)
- ☐ First ☐ Last (FEMA default) ☐ All
- ☐ LIDAR intensity returns
- ☐ Other simultaneous imagery

Vertical Accuracy (choose one)
- ☐ 1' contour equiv. ($Accuracy_z = 0.6$ ft.)
- ☐ 2' contour equiv. ($Accuracy_z = 1.2$ ft.)
- ☐ 4' contour equiv. ($Accuracy_z = 2.4$ ft.)
- ☐ 5' contour equiv. ($Accuracy_z = 3.0$ ft.)
- ☐ Other: $Accuracy_z$ = ___ ft.

Vertical accuracy at the 95% confidence level ($Accuracy_z$) = $RMSE_z$ x 1.9600 with normal distribution

Horizontal Accuracy (choose one)
- ☐ 1" = 500' equiv. ($Accuracy_r$ = 11' or 3.35 m)
- ☐ 1" = 1000' equiv. ($Accuracy_r$ = 22' or 6.7 m)
- ☐ $RMSE_r$ = 1 m
- ☐ $RMSE_r$ = _______

Horizontal accuracy at the 95% confidence level ($Accuracy_r$) = $RMSE_r$ x 1.7308

Data Model (choose one or more)
- ☐ Contours ☐ Mass points ☐ TIN (average point spacing = ___meters) *
- ☐ Cross sections ☐ Breaklines ☐ DEM (post spacing = ___meters)

* FEMA's standard DEM post spacing is 5-meters when mass points are supplemented with breaklines for hydraulic modeling. The TIN point spacing is typically smaller than the DEM post spacing to allow a denser network of irregularly-spaced points for interpolation of the uniformly-spaced DEM.

Horizontal Datum (choose one)
- ☐ NAD 27 ☐ NAD 83 (default)

Vertical Datum (choose one)
- ☐ NGVD 29 ☐ NAVD 88 (default)

Coordinate System (choose one)
- ☐ UTM ☐ State Plane ☐ Geographic

Units Note: For feet and meters, vertical (V) units may differ from horizontal (H) units
- ☐ Feet to ___ decimal places ☐ V ☐ H
- ☐ Meters to ___ decimal places ☐ V ☐ H
- ☐ Decimal degrees to ___ decimal places
- ☐ DDDMMSS to ___ decimal places

Feet are assumed to be U.S. Survey Feet unless specified to the contrary

Data Format (choose one or more)

Digital contour lines and breaklines
- ☐ .DGN
- ☐ .DO (DLG Optional)
- ☐ .DWG
- ☐ .DXF
- ☐ .E00
- ☐ .MIF/.MID
- ☐ .SHP
- ☐ SDTS
- ☐ TAB
- ☐ Other ___________

Mass points and TINs
- ☐ ASCII x/y/z
- ☐ ASCII with attribute data
- ☐ BIN
- ☐ TIN Arc/Info Export File
- ☐ Other ___________

DEMs
- ☐ ASCII x/y/z
- ☐ .BIL
- ☐ .BIP
- ☐ .BSQ
- ☐ .DEM (USGS standard)
- ☐ ESRI Float Grid
- ☐ ESRI Integer Grid
- ☐ GeoTiff
- ☐ .RLE
- ☐ Other ___________

File size or Tile size (choose one)
- ☐ File size ____ MB or 1 GB (max)
- ☐ Tile size _______ x ______ (specify feet or meters)
- ☐ Other tile size: ____________________________
- ☐ Buffer size: ____________________________

Other Quality Factors (optional, explain on separate page)
- ☐ Cleanness from artifacts
- ☐ Limits on size/location of void areas where there are no elevation data shown
- ☐ How elevations are to be shown for void areas
- ☐ Hydro-enforcement Bridges/culverts removed? ☐Yes ☐ No
- ☐ Other requirements

Figure 6-2. Digital Topographic Data Requirements Checklist (FEMA)

6-3. Topographic Survey Planning Checklist

Upon receipt of a user's request for a topographic survey, as part of the planning process it is best to logically resolve many of the variables associated with a proposed site. The following planning checklist may be used as a general outline for that process. This checklist may also be useful in reviewing a topographic survey request with the end user. The remainder of the sections in this chapter will address some of these items. (This checklist is taken from the Corps PROSPECT Survey III course).

PROJECT PLANNING
OBJECTIVE
- Identify considerations for planning and producing a survey.
- Identify issues to be addressed when requesting or discussing proposed work.

END-USE OF MAP OR DATA
- How will the data or map be used?
- Site planning
- Construction plans and specs
- Management
- GIS
- Will you count each tree, species, size?
- Plot boundary
- Compute areas

PROJECT PLANNING
- Thoroughly read request from user. (Request may be different than verbal agreement)
- What is the purpose of the survey?
- What did the site look like a year ago? What will it look like in one year?

SITE CONSIDERATIONS
- Has the requestor walked the site recently?
- (Not a drive-by performed 2 years ago.) Have you personally walked the site this season?
- Safety hazards to consider:
- Steep slopes
- Busy roads
- Flagger, road signs
- High speed railroad
- switching railroad
- Berries
- Poison oak, poison ivy, nettles
- Tide
- Weather patterns
- Local mentality

DELIVERABLE FORMAT
- Assume CADD environment
- Does file or map have to match existing data?
- What software will be used to view data?
- Engineering software for manipulation.
- Will a variety of output files be required?

COORDINATE SYSTEM
- Horizontal
- State plane
- State plane on what zone
- True state plane, or at ground surface
- Local
- Military coordinate system
- Recommend something that can be recovered. Perpetual coordinate system usually better.

STATIONING
- Stationing is a disjointed coordinate system where one axis is the STATION and the other is OFFSET, and the STATION axis rotates at every PI.
- Distances are usually ground distances.
- (State plane coordinates might have to be adjusted.)
- Great for linear surveys such as roads, railroads and levees.

VERTICAL COORDINATE SYSTEM
- NAVD 88 (specify adjustment date)
- MSL or NGVD 29 or NGVD 29 (XX)
- 1912 Adjustment
- MLLW
- City or Local
- Base
- Recommend a perpetual vertical system and conversion to datum used.

UNITS OF MEASURE

- Foot
- U.S. Survey Foot
- International Survey Foot
- Meter
- River mile, nautical mile
- Ground distances
- Grid distances

FILE TYPE

- .DGN
- .DWG
- .SHP
- ASCII
- .DXF
- .COT
- .TIF
- .WTIF

FILE SIZE

- Some files are just too large for PC.
- Match into existing or planning new software or computer.
- Does file size equate to sheet size?
- Are sheets necessary?

EXISTING CONTROL

- Decide what BM to hold ... 2 or more.
- Decide what horizontal to hold.
- Have these monuments been re-set?
- Always check between 2 or more existing monuments.
- Update reference ties.
- Protect during construction or relocate.

CONTROL MONUMENTS

- Set or reference permanent control
- The Same Control should be used for:
- Project boundary recovered or set
- Map for design
- Plans and specs
- Construction
- As-Builts
- Operation of facility as necessary
- Project boundary should be recovered or re-set.
- Construction as per EM 1110-1-1002
- Digging permit?
- Rebar below frost line
- Stamped or capped
- Reference ties
- Reference closest boundary
- Drive-to/To-reach
- Set in protected place and set witness post

CONTROL SURVEY

- Different procedure than mapping
- Whatever it takes to meet (EM 1110-1-1004, Chapter 3).
- Typically 2 sets of angles and differential levels
- Qualify monument coordinates with a level of accuracy.
- Archive

CONTROL DIAGRAM

- Original Monuments
- (Origination of horizontal and vertical)
- Monuments set (type and designation)
- Grid coordinates
- Coordinate System
- Ground Distance/Grid Distance/Combination Factor and Grid Factor, etc.
- Reference ties

CONTROL DIAGRAM Build control diagram for:

- Mapping
- Design
- Construction plans and specs
- Archive

DELIVERABLES

- X-section plots
- Topographic map
- Digital Terrain Model
- Ink on mylar
- Paper check plots
- Color
- Black/White
- Digital files only
- Digital file specifications/format
- Levels
- Font size
- Line weights
- Global origin
- Sheet size
- Title block format
- Seed files in relevant coord. Sys/units
- Boundary plat
- File with the county
- Metadata
- Field-book
- Computation files
- Daily reports

DELIVERABLES (CONTD)
- Project Surveyor's Report (pertinent data, relevant comments by locals)
- County reports
- Digital media type (CD, DVD, tape)

OTHER CONSIDERATIONS
- Manhole (MH) work
- Size, type of each pipe flowing into MH
- Direction of flow
- Invert and rim elevation of MH
- Confined space precautions
- Only survey what you can see.
- If locates, then call out as such.
- Bridge detail
- Standard bridge sketch
- Structural detail
- Cross-section upstream and downstream
- Profile across bridge deck + 300 ft
- Low steel elevation
- Orientation to flow
- Drill holes
- Locate before drilling. (Stake for digging permit.)
- Survey after drilling. (Provide coordinate and elevation on perpetual coordinate system.)
- Piezometers
- Where do you want the elevation?
- Are they locked? Have they been located or read recently?
- Photographs of site
- Keep a logical record.
- Helpful for office when mapping.
- Show nearest utility hook-ups.
- Water
- Fire Hydrants
- Power
- Sanitary, storm etc.
- Keys
- Do we need any keys for access?
- Right of entry
- Knock on the door first
- Tree/brush clearing permits
- ROE in hand

SECURITY
- Notify installation/project office in advance (need POC)
- Name, purpose, duration
- Restricted area
- Security escort required?
- Security briefing
- E-mail
- Clothing requirement, safety clothing
- Radio contact, pager

SPECIAL CONDITIONS Survey or map during:
- Low pool
- Maximum pool
- Winter
- After or before Leaf Drop
- Conform to base or project operations.
- Base operations
- Flight schedule
- Operation schedule (spillway at dam)
- Low tide, high tide
- Not during:
  - Duck hunting season, deer hunting season
  - Calving or nesting season
  - Fish migration

SCHEDULE
- Is this time critical?
- Could we save money by waiting?
- Produce field-work now, and office later.
- Will work be contracted?
- How long to advertise, select, negotiate?
- Fiscal year (dated money)

OPTIONS TO COMPLETE WORK
- In-House
- IDC
- Credit card
- Neighboring districts
- Other engineering contracts in the district
- Other agencies

FUNDING
- Seed money to provide intelligent estimate
- Is proposed work probable?
- What kind of estimate is required?
- Format of estimate
- Cover your estimate
- Clearly state all assumptions
- Provide proposed Schedule of Obligation and Expenditure, if contracted.

PROJECT PLANNING, OFFICE
- Research
- Control
- In-house
- State
- County
- Municipality or Military Installation
- Land corners
- Previous work in area

SAFETY ISSUES
- Weather
- Gunnery
- Operations
- Tides
- Bugs
- Mud, Sand
- UNEXO
- HTRW Site Safety Plan

EQUIPMENT
- Radios
- Batteries
- Cables
- Chargers
- Place to charge
- Water jug
- First Aid/CPR
- Metal detector
- Chain saw
- Drill
- Waders or hip boots
- Work vest
- Long rod
- Steel tape
- Pocket tape
- Total station
- Reflectorless
- Robotic
- Data collection
- Need to download daily.
- Computer with software and place
- Level
- Prism pole
- Triple prism
- Lead line
- GPS
- Is site GPS friendly?

VEHICLES
- 4 x 4
- ATV & trailer
- Boat
- Skiff
- Work boat
- Fisherman's tube
- Parking at project or secured at hotel

MATERIALS
- Hubs/Stakes
- Lath
- Flagging
- Paint
- Nails
- Monuments
- Rebar

6-4. Rights-of-Entry

When entering property to conduct a survey, rights of the property owner will be respected. The following paragraphs outline some minimum guidelines that should be followed.

a. Permission. Whenever necessary, permission to enter a military installation and other private property may be acquired by the District prior to entering such property. While on the military installation, members of the survey crew will adhere to all of the stipulations (e.g., rules, regulations, directives, verbal guidance, etc.) set forth by the Installation Commander or his designated representative. The same basic guidelines are applicable when the right to enter private property is given.

b. Protection of property. Government and private property shall be protected at all times. Every effort should be made not to damage or cut trees, shrubs, plants, etc. on the property. If line cutting or other modifications must be done, the Installation Commander, or in the case of private property, the private property owner, is the only person who can grant permission to do so. It shall be standard practice that property entered shall be returned to its condition prior to entry once the survey is completed. Gates and other structures should be left in the position in which they were found prior to entry. If a gate is closed, do not leave it open for any long period of time. Return all borrowed property (e.g., keys, maps, etc.) as instructed by the property owner or designated representative.

c. Monuments. Survey points should be placed in such a way as to not obstruct the operations of an installation or the property owners, or be offensive to their view. Monuments set as a result of the survey should be set below ground level to prevent damage by or to any equipment or vehicles; especially grass cutting tractors. Extra care must be taken when setting a survey point at or near airports. Any temporary marks set on military installations or private property will be removed as soon as possible after the survey work is completed, or at the request of the Installation Commander, property owner, and/or designated representative. Permission should be obtained before painting permanent aerial mapping targets on paved surfaces.

6-5. Sources of Existing Geospatial/Survey Data

When a request for a survey of a given project site is received, the first effort should be to research the files to ascertain if a survey of the same site has already been performed. Policies and procedures for performing searches of geospatial clearinghouse databases are prescribed in EM 1110-1-2909 (*Geospatial Data and Systems*). However, given the highly detailed scale of topographic surveys, and the need for current conditions, it is highly improbable that an archived survey of sufficient detail can be found at these geospatial data shopping sites. Regardless, NSRS control will still be needed to reference the topographic mapping. A variety of databases can be accessed to obtain horizontal and vertical control from various local, state, and federal agencies. One or more of the following sources of existing geospatial data may need to be researched before performing a topographic survey. These files may be located in the District Office, the installation or base, county clerk's office, or a local public works/utility company.

- Installation As-built drawing files. The requesting installation may have detailed hard copy or digital files of topographic surveys, utility drawings, or real estate tract maps.

- District Office files. Archived drawing files for the project site.

- Aerial photo archives.

- Utility drawings. Electric, sanitary, storm, cable, telephone, fiber optic, etc. (Figure 6-3).

- Recorded plats and related real property surveys. Consult local county courthouse, District Real Estate Division files, local surveyor's archival files, etc.

- USGS topographic quadrangle maps. USGS quadrangle maps may be used for general location references. Excerpts of these maps can be downloaded at sites such as www.topozone.com. General small-scale orthophoto imagery can also be downloaded from a number of web sites, if this imagery is needed for a background to design plans drawings and specifications.

- NGS control. Published National Geodetic Survey control can be downloaded at www.ngs.noaa.gov. This site allows simple search options for all NSRS control points in the region of the project.

- State, county, city, and regional agency control. Some states and regional/local agencies maintain web sites for searching control in their areas.

• District control. Corps control on a project or Army installation may be available in archived files.

The FGDC National Geospatial Data Clearinghouse is a potential source for imagery data within or surrounding a project site. The Geospatial Data Clearinghouse is a collection of over 250 spatial data servers that have digital geographic data primarily for use in Geographic Information Systems (GIS), image processing systems, and other modeling software. Generally, at this time the data is of small-scale resolution, which means there are few uses for large-scale topographic mapping. These data collections can be searched through a single interface based on their descriptions, or "metadata." The Clearinghouse can be reached through a link on the FGDC web site: http://www.fgdc.gov.

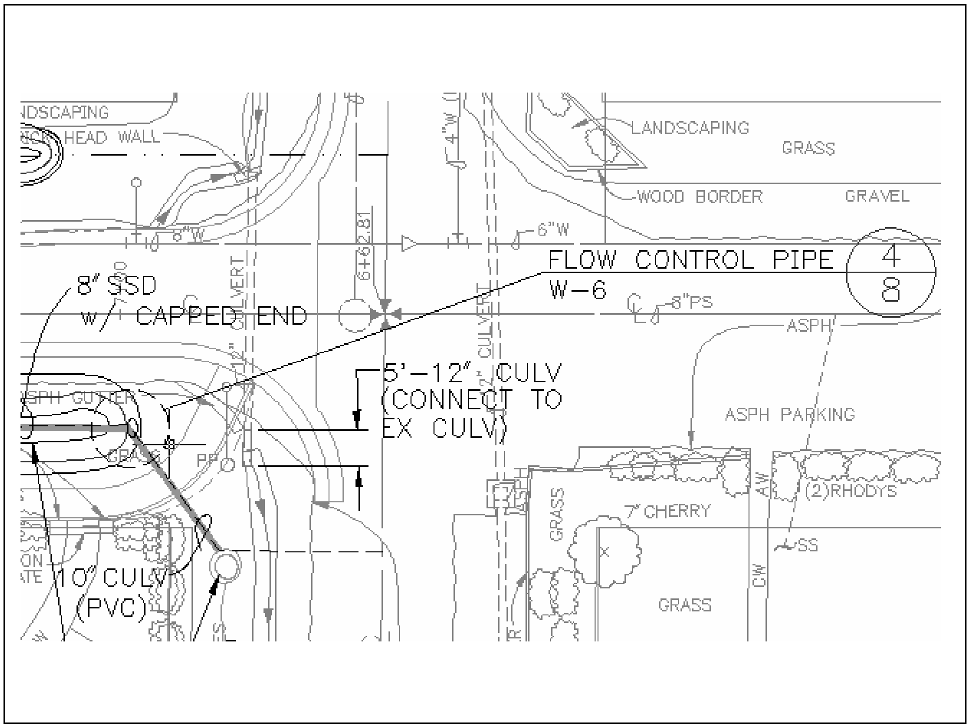

Figure 6-3. Portion of a typical as-built utility map depicting proposed modifications

6-6. Project Control for Topographic Detail Surveys

Topographic surveys of facilities, utilities, or terrain must be controlled to some reference framework, both in horizontal and vertical. This reference framework should consist of two or more permanently monumented control points and/or benchmarks located in the vicinity of the project. These project control points can then be used to perform supplemental topographic surveys of the project. This concept is illustrated in Figure 6-4 below. In this example of a survey site located along the Ohio River, NSRS control is brought in from three existing points using static GPS observations. A single point on the western end of the survey site is positioned. A baseline in the project area is established from the westernmost point using GPS. From these two intervisible points, subsequent topographic detail is surveyed using either a total station or RTK methods. LIDAR scans of the bridge across the Ohio River could be made relative to points set from the westernmost new point. In CONUS, connections are usually made to the NSRS. In OCONUS locales, connections to local reference frameworks can be made. Simple references to the satellite-based WGS-84 framework system may be also used, using a UTM grid for local reference. Vertical control is usually established relative to the nearest existing benchmarks. In

Figure 6-4 below, the points on the ends of the baseline would be tied in by differential levels to two or more or the local benchmarks shown.

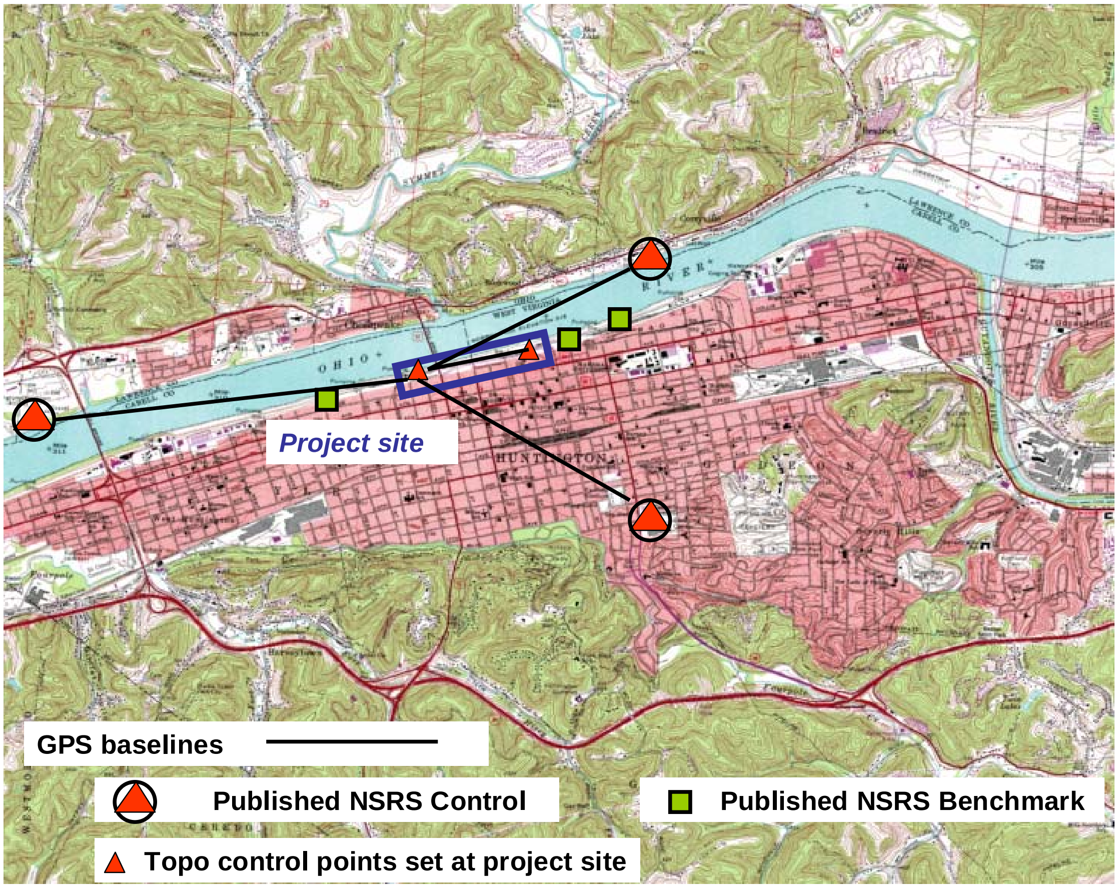

Figure 6-4. Project control: NSRS and local control

a. Project control relative accuracy. In general, horizontal and vertical accuracy of the control points used to control topographic surveys need only be to Third-Order, relative to themselves. In practice, if these control points in and around the project site have been interconnected by total station traverse, differential leveling, or static/kinematic DGPS techniques, their relative accuracy will be far greater--upwards of 1:50,000 to 1:100,000 type closures are expected. Positional accuracies within a project site should be around the ± 0.2 ft level in X-Y, and better than ± 0.1 ft in the vertical.

b. Project control absolute accuracy. The absolute accuracy of project control is that defined relative to some local, statewide, or nation-wide reference framework. These frameworks might be the NSRS that is maintained be the National Geodetic Survey or an installation geodetic network that was in turn connected to the NSRS. Maintaining a good relative accuracy with an adjoining installation project control network is far more important than accurate connections to distant NSRS networks. Likewise, connections to adjoining property boundary monuments are significantly more critical than connections to distant NSRS networks.

c. Boundary control. Topographic surveys involving real property boundaries must always be connected to established property corners, section corners, or adjoining right-of-way boundaries. Locations of structures, buildings, roads, utilities, etc. must be shown relative to the property boundaries. Likewise, stakeout of planned construction must be performed relative to these boundaries--and surveyed relative to applicable property corner pins. NSRS framework coordinates may be placed on property corner marks; however, subsequent stakeout work should never be performed relative to distant NSRS control--in other words, one should always occupy and/or connect to the nearest adjoining property boundary corners, as shown in Figure 6-5.

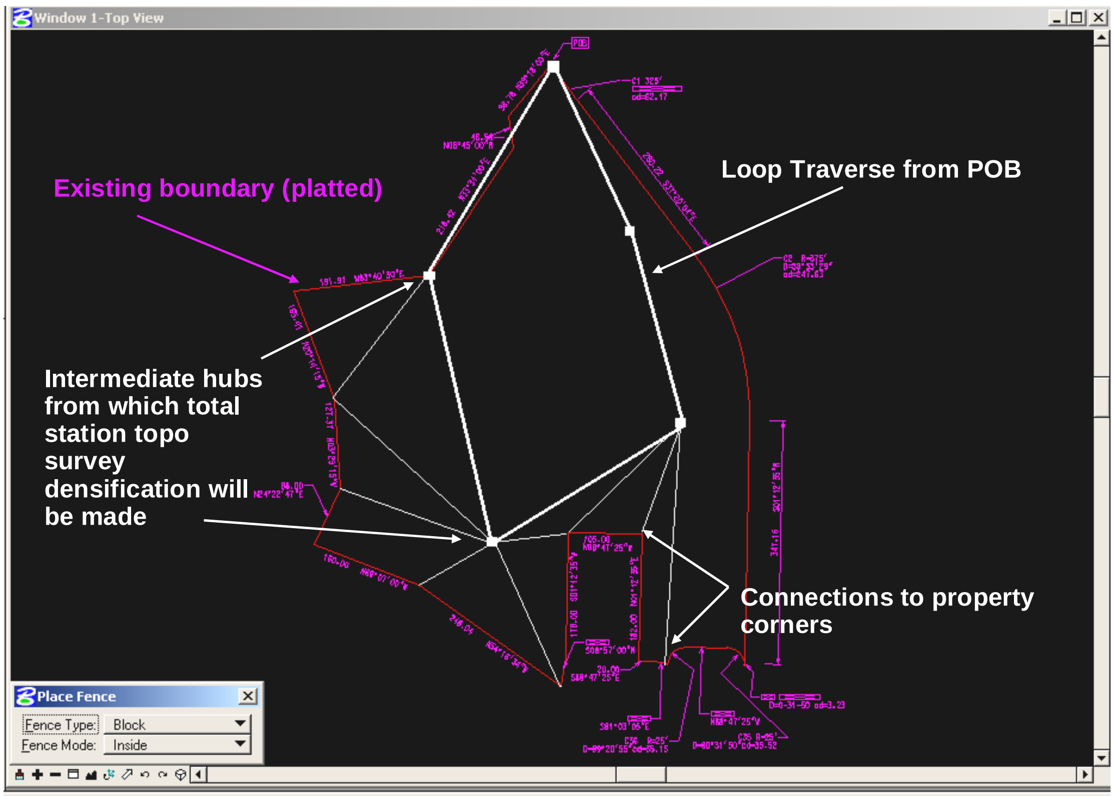

Figure 6-5. Setting additional topographic survey control points relative to platted property corners

d. Local project control. On some occasions, there is no existing horizontal or vertical control within the immediate vicinity of a project. Two options are available:

- Perform detailed surveys relative to an arbitrary coordinate system established for the project--e.g., set two permanent reference points, assume arbitrary coordinates of 5,000-10,000-100 (X-Y-Z) for one of the marks.

- Perform traverse, leveling, and/or GPS control surveys to bring in NSRS referenced control to the project site.

The first option listed above used to be more common; however, with the ease of extending control with GPS (either autonomous or differential), it is now fairly simple to establish some form of NSRS control on a project; or, at minimum, reference to the WGS 84 ellipsoid.

6-7. Establishing NSRS Control at a Project Site

A variety of factors must be considered in deciding whether and how to connect project sites to an external spatial coordinate network. These include:

- Cost: Bringing distant horizontal and vertical control to a project site can be costly, and may exceed the cost of performing the detailed topographic survey itself.

- Policy. Command, Agency, District, or Installation policy may mandate that all site plan work shall be referenced to the NSRS. If this is the case, then it is up to the surveyor to perform this connection in the most cost-effective manner as possible.

- Accuracy (horizontal and vertical). The horizontal and vertical accuracy of topographic features relative to the NSRS must be rigorously and sensibly defined. Most project sites have no real requirement for rigorous connections to a NSRS. For example, the horizontal location of a Reserve Center motor pool building need not have precise geographic coordinates relative to the NSRS. However, the location of a lock guidewall must be accurately located relative to the NSRS since this feature will be depicted on independent navigation charts. Likewise, the first floor elevation of the motor pool building relative to NGVD 29 is of little significance if the Reserve Center is located well outside any flood plain. For example, absolute NSRS positional accuracies of the motor pool building would be adequate at the ± 10 ft level in X-Y, and ± 3 ft in the vertical, whereas its local topographic survey accuracy relative to an adjoining property line would be around the ± 0.1 ft level in X-Y, and a floor elevation better than ± 0.02 ft relative to local utility connections.

- Distance from NSRS network. The distance useable published horizontal control points or vertical benchmarks are from the project site will have an impact on cost. In particular, if a distant benchmark requires a lengthy level line to bring in accurate vertical control, costs can rapidly escalate. More options are available for bringing in horizontal control to a project site, such as GPS static options using CORS networks.

Depending on many of the factors listed above (and many others), the method and accuracy of bringing in project control can be designed. The following paragraphs describe some of the common techniques that can be employed in establishing horizontal and vertical control relative to a NSRS network.

6-8. Project Control Densification Methods

a. Horizontal control. Horizontal control is most effectively connected to the NSRS published network into a project site by one of the following methods:

- Traverse surveys

- Static GPS surveys

- Kinematic GPS surveys

Traverse surveys with a total station are practical if the existing control is fairly close to the project site, i.e., within a few turning point setups. General procedures for performing conventional traverse surveys are covered in Chapter 3. If traverse surveys would take more than a few hours, then a static GPS observation may prove more practical. At least two external NSRS network points should be occupied. Alternatively, a static GPS survey could be conducted at a point set on the project site using the NGS

CORS network to adjust the point. Since most topographic site plan mapping surveys require only Third-Order accuracy relative to the NSRS, short-term (1 or 2 hour) GPS observations are normally the most cost-effective methods for extending control to a project site. Refer to EM 1110-1-1003 (*NAVSTAR GPS Surveying*) for details on performing and adjusting static GPS surveys.

b. Vertical control. If vertical control is required to a higher accuracy than can be achieved using GPS survey techniques, then conventional leveling methods must be used. Depending on the distance of the level run, Third-Order methods are usually sufficient. Either single-wire or digital leveling may be used. See EM 1110-1-1009 (*Structural Deformation Surveying*) if more accurate leveling methods are required--e.g., precise leveling with two-sided invar rods. Total station trigonometric leveling may be performed over short distances.

6-9. Extending Control from a Local Project or Installation Network (Patrick AFB)

Most topographic surveys are performed on existing installation or civil works project sites where NSRS or boundary control is readily available. Depending on the distance of this control from the survey site, either total station traverse or static GPS surveys are used to establish local control. Vertical control will typically be brought in by running Third Order levels from two existing benchmarks. If boundary surveys are required, then all property corners should be recovered and tied in as part of the survey. Figure 6-6 below (from a Trimble Geomatics Office screen capture) illustrates a constrained adjustment network for a Louisville District in-house control survey at an Army Reserve Center at Patrick AFB, Florida. GPS control is established from one-hour static and 5 to 15 min fast-static observations at three fixed NSRS control points--TECH 1961 (N-E-h) from the south , GPS 1009 (N-E) from the north, and BM PC1000 (e) from the south; where "N-E" are fixed horizontal coordinates, "h" is a fixed ellipsoidal height, and "e" is a fixed orthometric elevation. Station PAT1 at the Patrick AFB site is thereby controlled. From PAT1, 10 additional control points within the site are radiated from short-term (less than 5 min) kinematic GPS observations. These points are used as subsequent total station occupations.

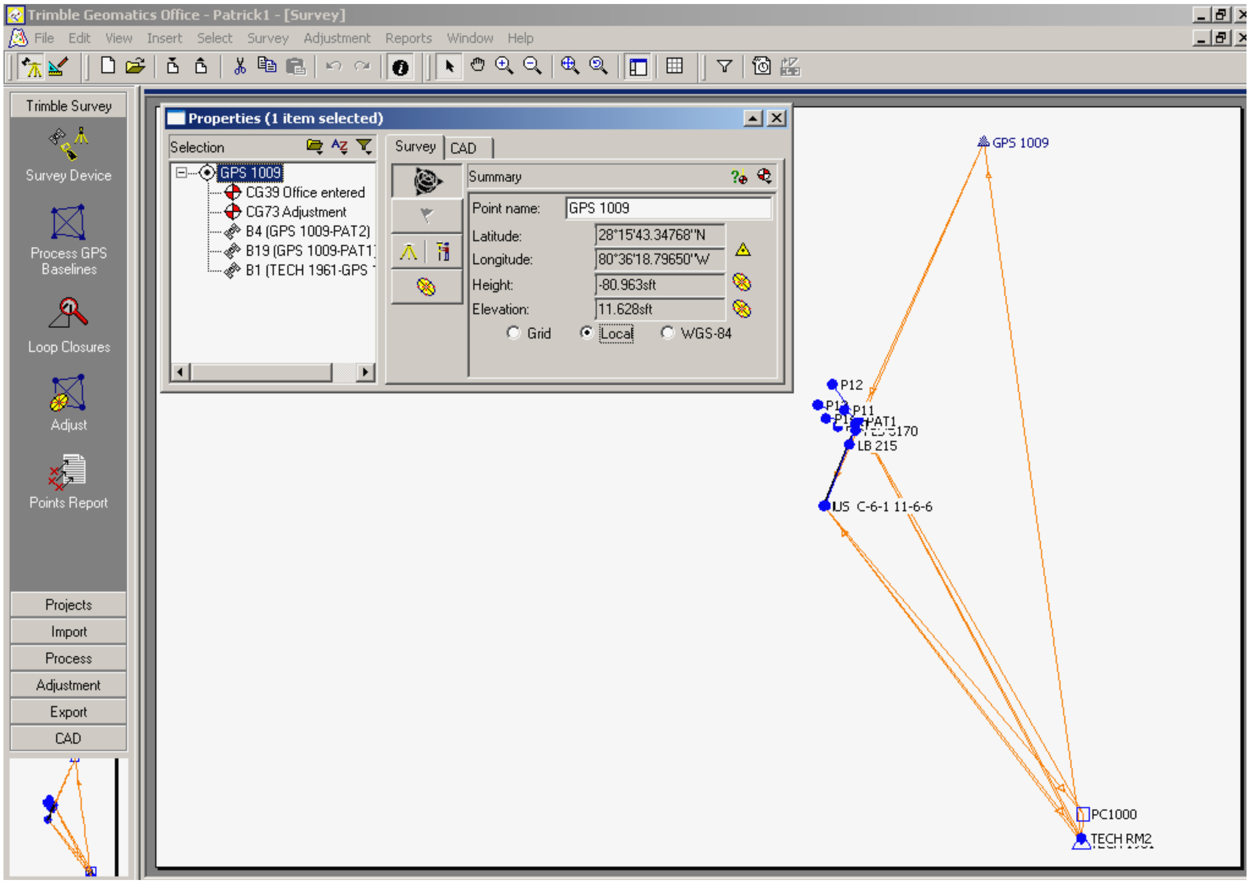

Figure 6-6. Horizontal and vertical control extended to project site from external NSRS points (Patrick AFB, Florida--Louisville District 2004)

Figure 6-7 below shows various control and topographic observations that were performed on the Patrick AFB survey. On this project, both total station and RTK topographic surveys were performed. The occupied radial points were positioned by fast static GPS observations from the primary installation/NSRS control point some 2,500 ft south of the site. The blue lines represent GPS baselines (Fast Static or RTK) and the green lines are terrestrial (total station) observations. All the observations were imported into TGO for a constrained adjustment (only redundant control points receive any adjustment--the radial RTK or total station observations are not adjusted).

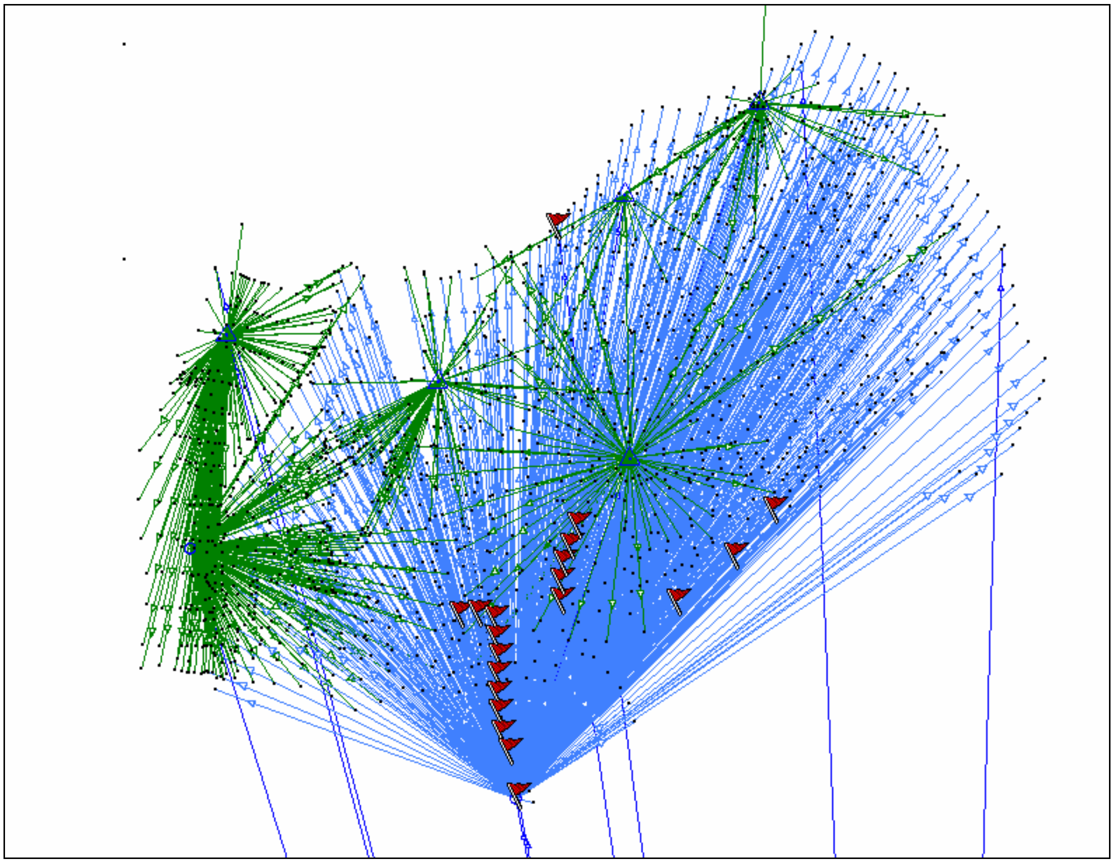

Figure 6-7. Total Station and RTK surveys at Patrick AFB (Louisville District 2004)

6-10. Extending Control from a Distant Network Using Continuously Operating Reference Stations (CORS)

The National Geodetic Survey coordinates the maintenance of a permanent network of continuously operating GPS receivers that can be used to establish NSRS control at virtually any place in CONUS. The use of CORS stations eliminates the need to occupy full baselines, as in the previous example. A single GPS receiver is set up at a primary control point in the project site, and 1 to 2 hour static GPS observations are recorded. These observations become the end of any number of selected baselines using stations in the CORS network. Static GPS observations made at a project site can be adjusted to any number of nearby CORS stations, using the NGS User Friendly CORS Web site, which is linked through the NGS Web Site at: http://www.ngs.noaa.gov .

a. The following example illustrates extending NSRS control to a project site using the CORS data network maintained by the NGS. Figure 6-8 below depicts an extension of NSRS control to a remote site where a detailed topographic survey is required. The point of this example is to illustrate a practical, rapid (one hour observing time), and cost-effective method of extending NSRS horizontal and vertical control into a project site. In this example (a structure survey on a remote mountain in Pennsylvania), a one-hour static GPS observation was made at a monument set near the facility to be surveyed. The specified NSRS absolute accuracy required was only ± 10 feet horizontal and ± 3 feet vertical. The one-hour static observation was connected to six CORS stations as shown below. The six baselines were reduced and an adjusted position for the topographic reference point was computed using least squares software.

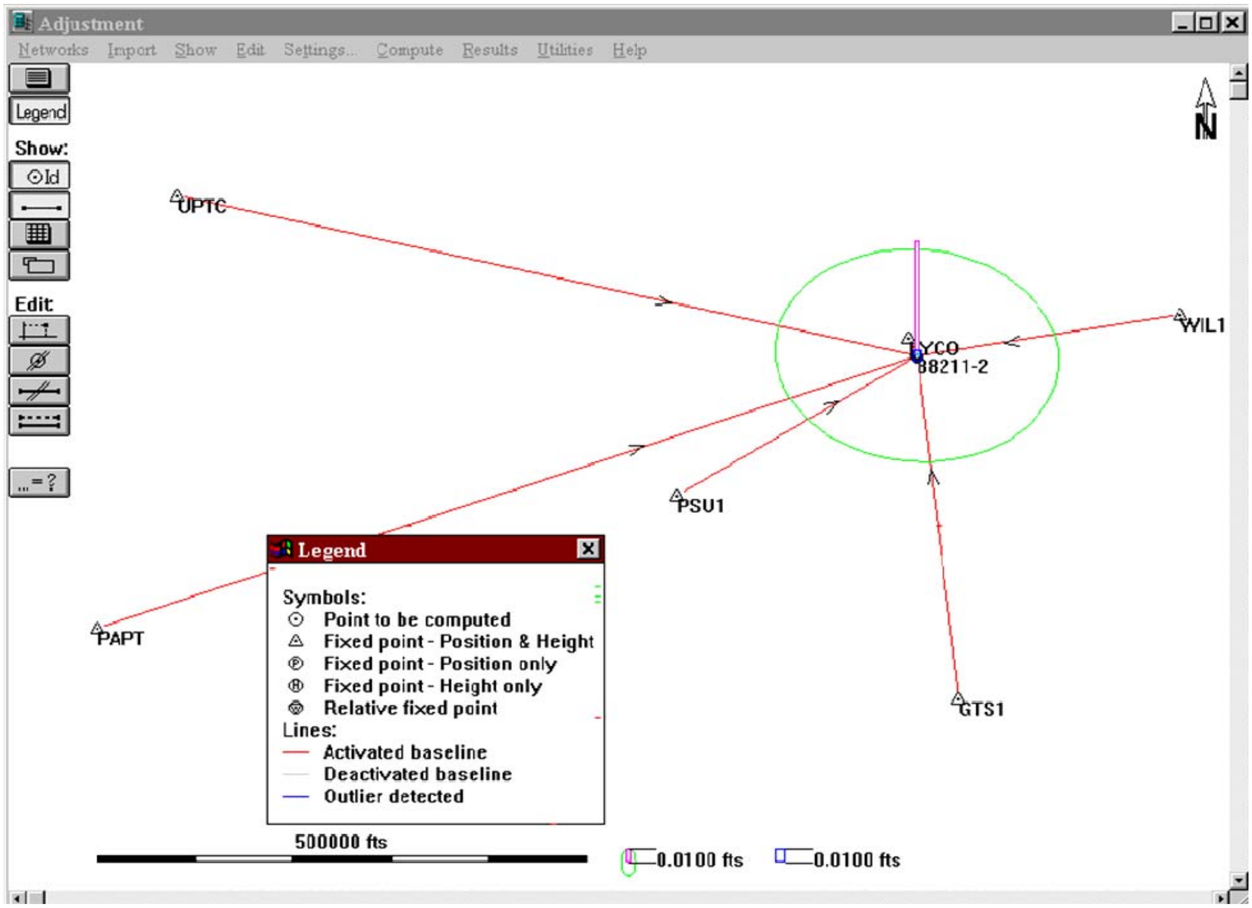

Figure 6-8. Connections to multiple CORS stations to adjust coordinates of a remote point (Leica SKI)

b. Figure 6-8 above shows the unknown control point "88211-2" being connected to six CORS stations at various locations in Pennsylvania--PAPT, PSU1, GTS1, UPTC, WIL1, and LYCO. RINEX data recorded for each of these CORS stations was downloaded from the Internet and each of the six baselines was reduced using standard baseline reduction software. A standard constrained adjustment using the weighted baseline reduction data is then performed to arrive at the adjusted position of the point "88211-2." The output of this adjustment is shown below with notes shown in blue italics:

```
Adjustment type          :  Constrained
Number of observations   :  18                  [6 baselines -- X, Y, and Z]
Number of unknowns       :  3
Degrees of freedom       :  15
Number of groups         :  1
88211-2          Lat:  41 11 30.397202 N ±   0.00960 [m]  ± 0.03 ft
                 Lon:  76 58 35.163335 W ±   0.01280 [m]  ± 0.04 ft
                 Hgt:         517.6770 m ±   0.01286 [m]  ± 0.04 ft
```

The above result indicates that the resultant CORS-adjusted position has a high relative accuracy estimate--at the ± 0.1 ft level. This accuracy is more than adequate to reference the horizontal location of subsequent total station observations made from "88211-2." The height shown (517.677 m) may have adjusted to the ± 0.1 ft level, but this elevation is based on the WGS 84 ellipsoid height reduced to NAVD 88 using the published geoid model (GEOID 03) at this location--a predicted correction. Thus, while this CORS-adjusted elevation is well within the ± 3 ft accuracy specification, use of the predicted geoid model may degrade the absolute accuracy to no better than ± 0.5 ft. If the project required a better vertical accuracy relative to adjacent utility systems, then conventional differential level lines should be run rather than use GPS-derived vertical elevations.

c. The following output from this CORS connection scheme shows a Leica SKI "Mean Position" option based on the six baselines (the mean position is not the same as the least squares position). Also shown are the differences in Lat-Long-Hgt for each baseline relative to the mean position. These differences clearly indicate that the more distant baselines (PAPT, GTS1, and UPTC) are of lesser quality; however, they would provide results well within the desired tolerances if used separately. In practice, not all six of these CORS observations would have been used on this project--they are used in this example for illustrative purposes to show that even CORS points 100 to 200 miles distant can provide fairly reliable results. Since CORS point LYCO was less than 10 miles away from the project site, and has a fixed baseline solution (all the others were "float" solutions), this CORS point and a second check point (e.g., PSU1) would have been adequate in practice. It is always advisable to include a third CORS site for a blunder check. CORS-derived positions can be computed the same day as the observations are made.

```
Mean coordinates and differences:
---------------------------------

Point id: 88211-2

WGS84 Coordinates:
[WGS 83Lat-Long/NAVD 88 Hgt       Geocentric coordinates]
Lat:      41 11 30.39723 N    X:    1083261.795 m
Lon:      76 58 35.16313 W    Y:   -4683333.242 m
Hgt:             517.695 m    Z:    4178814.491 m

Reference  Date(YY/MM/DD)       dLat         dLon         dHgt
--------------------------------------------------------------------------
LYCO      04/05/28 12:58:25   -0.002 m      0.000 m     -0.005 m  fixed
WIL1      04/05/28 13:04:35   -0.003 m      0.090 m      0.078 m
GTS1      04/05/28 12:58:25    0.002 m      0.106 m      0.095 m
PAPT      04/05/28 12:58:25   -0.014 m     -0.077 m      0.175 m  > 150 miles
UPTC      04/05/28 13:05:10   -0.022 m      0.123 m      0.060 m
PSU1      04/05/28 12:58:25   -0.022 m     -0.025 m      0.077 m
```

d. In obtaining CORS data sheets from the NGS, care must be taken to use the correct published coordinates shown on the sheet and input those values in the GPS adjustment program. The typical datasheet that is downloaded with a CORS dataset is shown below for a point in Ohio near Gallipolis Lock and Dam on the Ohio River--Figure 6-9 on the next page. On this example, the coordinates for antenna phase center (ARP) are used (note options regarding use of L1 and L2 phase centers). Ignore all "ITRF" positions--use only published NAD 83 positions. The ellipsoid height on this CORS sheet (169.501 m) is based on GPS observations at this point and is referenced to NAD 83. The NGS Data Sheet (Figure 6-10) for this point (PID = DF4048) shows its GEOID 03 height. No NAVD 88 elevation is indicated since this CORS ARP point has not been connected to the vertical network. These CORS position and ellipsoid heights can be changed and may not be the same as the downloaded RINEX position and ellipsoid heights. Thus, care must be taken when using CORS stations to ensure that coordinates used in the adjustment are those published. In rare cases, errors in published CORS ellipsoid heights have been encountered; thus, redundant CORS points are advised.

e. Azimuth orientation at the topographic project site is easily performed as part of the process of bringing in CORS control. A second GPS receiver is set up at a marked point 500 to 1,000 ft distant from the first GPS point. GPS observations over the short baseline are made concurrently with the CORS baseline connections. The fixed solution over this short baseline will provide adequate azimuth orientation for subsequent topographic work at the project site. (Note that a solid fixed solution is required over this baseline). Either end of the baseline can be used to fix the CORS-derived X-Y-Z position. The absolute accuracy over a 1,000 ft baseline will be between 10 and 30 seconds, depending on the quality of the short baseline solution. This azimuth is adequate assuming the survey site is small and no real property connections are required. If the site has deeded boundary alignments (e.g., bearings shown along a road or boundary), then these deeded bearings should be used for azimuth reference if this alignment is the established reference. GPS derived azimuths would have to be corrected to fit the local orientation.

```
        Antenna Reference Point(ARP): GALLIPOLIS CORS ARP
        -------------------------------------------------
                            PID = DF4048

 ITRF00 POSITION (EPOCH 1997.0)
 Computed in Feb., 2003 using 24 days of data.
     X =    668399.969 m     latitude     =  38 50 39.17620 N
     Y =  -4929212.710 m     longitude    = 082 16 40.10632 W
     Z =   3978967.616 m     ellipsoid height =  168.250   m

 ITRF00 VELOCITY
 Predicted with HTDP_2.7 February 2003.
     VX =  -0.0164 m/yr      northward =   0.0012 m/yr
     VY =  -0.0017 m/yr      eastward  =  -0.0165 m/yr
     VZ =   0.0011 m/yr      upward    =   0.0003 m/yr

 NAD_83 POSITION (EPOCH 2002.0)
 Transformed from ITRF00 (epoch 1997.0) position in Feb., 2003.
     X =    668400.506 m     latitude     =  38 50 39.14896 N
     Y =  -4929214.152 m     longitude    = 082 16 40.09229 W
     Z =   3978967.747 m     ellipsoid height =  169.501   m

 NAD_83 VELOCITY
 Transformed from ITRF00 velocity in Feb., 2003.
     VX =   0.0000 m/yr      northward =   0.0000 m/yr
     VY =  -0.0001 m/yr      eastward  =   0.0000 m/yr
     VZ =   0.0000 m/yr      upward    =   0.0000 m/yr
______________________________________________________________________________

 L1 Phase Center of the current GPS antenna: GALLIPOLIS CORS L1 PC C
 -------------------------------------------------------------------
 The D/M element, chokerings, radome antenna
 (Antenna Code = TRM29659.00     UNAV) was installed on 11/14/02.
        The L2 phase center is 0.020 m above the L1 phase center.
                            PID = DF9327
 ITRF00 POSITION (EPOCH 1997.0)
 Computed in Feb., 2003 using 24 days of data.
     X =    668399.982 m     latitude     =  38 50 39.17622 N
     Y =  -4929212.792 m     longitude    = 082 16 40.10624 W
     Z =   3978967.684 m     ellipsoid height =  168.358   m

 The ITRF00 VELOCITY of the L1 PC is the same as that for the ARP.

 NAD_83 POSITION (EPOCH 2002.0)
 Transformed from ITRF00 (epoch 1997.0) position in Feb., 2003.
     X =    668400.519 m     latitude     =  38 50 39.14899 N
     Y =  -4929214.235 m     longitude    = 082 16 40.09221 W
     Z =   3978967.815 m     ellipsoid height =  169.609   m

 The NAD_83 VELOCITY of the L1 PC is the same as that for the ARP.
______________________________________________________________________________
 * Latitude, longitude, and ellipsoid height are computed from their corresponding
Cartesian coordinates using dimensions for the GRS 80 ellipsoid:
semi-major axis = 6,378,137.0 meters  flattening  =1/298.257222101
 * WARNING: Mixing of antenna types can lead to errors of up to 10 cm. in height
unless antenna-phase-center variation is properly modeled.
```

Use NAD 83 POSITION of ARP in Adjustment

Figure 6-9. CORS antenna reference data

The NGS Data Sheet

See file dsdata.txt for more information about the datasheet.

```
DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.09
1        National Geodetic Survey,   Retrieval Date = NOVEMBER 16, 2004
DF4048 ***********************************************************************
DF4048  CORS         -  This is a GPS Continuously Operating Reference Station.
DF4048  DESIGNATION -  GALLIPOLIS CORS ARP
DF4048  CORS_ID      -  GALP
DF4048  PID          -  DF4048
DF4048  STATE/COUNTY-  OH/GALLIA
DF4048  USGS QUAD    -  RODNEY (1983)
DF4048                         *CURRENT SURVEY CONTROL
DF4048  ___________________________________________________________________
DF4048* NAD 83(CORS)-  38 50 39.14896(N)    082 16 40.09229(W)     ADJUSTED
DF4048* NAVD 88      -
DF4048  ___________________________________________________________________
DF4048  EPOCH DATE  -        2002.00
DF4048  X            -     668,400.506 (meters)                     COMP
DF4048  Y            -  -4,929,214.151 (meters)                     COMP
DF4048  Z            -   3,978,967.746 (meters)                     COMP
DF4048  ELLIP HEIGHT-          169.50  (meters)          (02/??/03) GPS OBS
DF4048  GEOID HEIGHT-          -33.71  (meters)                     GEOID03
DF4048  HORZ ORDER  -  SPECIAL (CORS)
DF4048  ELLP ORDER  -  SPECIAL (CORS)
DF4048
DF4048.ITRF positions are available for this station.
DF4048.The coordinates were established by GPS observations
DF4048.and adjusted by the National Geodetic Survey in February 2003.
DF4048.The coordinates are valid at the epoch date displayed above.
DF4048.The epoch date for horizontal control is a decimal equivalence
DF4048.of Year/Month/Day.
DF4048.The PID for the CORS L1 Phase Center is DF9327.
DF4048
DF4048.The XYZ, and position/ellipsoidal ht. are equivalent.
DF4048
DF4048.The ellipsoidal height was determined by GPS observations
DF4048.and is referenced to NAD 83.
DF4048.The geoid height was determined by GEOID03.
DF4048
DF4048;                    North         East     Units Scale Factor Converg.
DF4048;SPC OH S     -    93,742.541   619,289.825   MT  0.99998005   +0 08 27.6
DF4048
DF4048!             -  Elev Factor  x  Scale Factor =   Combined Factor
DF4048!SPC OH S     -   0.99997341  x   0.99998005  =   0.99995346
DF4048
DF4048                          SUPERSEDED SURVEY CONTROL
DF4048.No superseded survey control is available for this station.
DF4048
DF4048_U.S. NATIONAL GRID SPATIAL ADDRESS: 17SLD8910900264(NAD 83)
DF4048_MARKER: STATION IS THE ANTENNA REFERENCE POINT OF THE GPS ANTENNA
DF4048
DF4048                          STATION DESCRIPTION
DF4048'DESCRIBED BY NATIONAL GEODETIC SURVEY 2003
DF4048'STATION IS A GPS CORS.  LATEST INFORMATION INCLUDING POSITIONS AND
DF4048'VELOCITIES ARE AVAILABLE IN THE COORDINATE AND LOG FILES ACCESSIBLE
DF4048'BY ANONYMOUS FTP OR THE WORLDWIDE WEB.
DF4048'   FTP CORS.NGS.NOAA.GOV: CORS/COORD  AND  CORS/STATION_LOG
DF4048'   HTTP://WWW.NGS.NOAA.GOV  UNDER PRODUCTS AND SERVICES.
```

Figure 6-10. NGS Data Sheet

6-11. On-Line Positioning User Service (OPUS)

OPUS is a free on-line baseline reduction and position adjustment service provided by the National Geodetic Survey. OPUS provides an X-Y-Z baseline reduction and position adjustment relative to three nearby national CORS reference stations. It performs the solution similarly to the manual adjustment illustrated above and can be used for establishing accurate horizontal control relative to the NSRS. It is simpler to operate in that only the user's observed data needs to be uploaded as opposed to downloading three or more CORS RINEX files. It can also be used as a quality control check on previously established control points. OPUS input is performed "on-line" by entering a required minimum period static, dual-frequency GPS RINEX, or other acceptable native format data. The resultant adjustment is returned in minutes via e-mail. Either the ultra-rapid or the precise ephemeris is used for the solution. OPUS is accessed at the following web page address: www.ngs.noaa.gov/OPUS. The various data on the web page screen are entered, e.g., e-mail address, RINEX file path, antenna height, and local SPCS code. The antenna height in meters is the vertical (not slope) distance measured between the monument/benchmark and the antenna reference point (ARP). The ARP is almost always the center of the bottom-most, permanently attached, surface of the antenna. If 0.0000 meters is entered for the height, OPUS will return the position of the ARP. The type of antenna is selected from the drop down menu. OPUS computes an average solution from the three baselines. NGS baseline reduction software is used for the solutions. Output positions are provided in both ITRF and NAD 83. An overall RMS (95%) confidence for the solution is provided, along with maximum coordinate spreads between the three CORS stations for both the ITRF and NAD 83 positions. An orthometric elevation on NAVD 88 is provided using the current geoid model. The orthometric accuracy shown is a function of the spread between the three redundant baseline solutions. OPUS is also recommended as a check on existing USACE control.

6-12. Establishing Approximate Control for an Isolated or OCONUS Construction Project

When confronted to perform a topographic survey for design or construction at a remote (OCONUS) project site, the following options are available:

- Establish a local (arbitrary) coordinate system--e., g., set and mark a primary point with X-Y-Z coordinates 10,000-10,000-100 (meters or feet). (It is recommended that the arbitrary X-Y coordinates be sufficiently different (e.g., 5,000-10,000) to avoid potential confusion between coordinates. Also ensure that negative coordinates will not occur over the project site).

- Set and mark a secondary point 500 to 1,000 ft distant for azimuth orientation.

- Establish the azimuth orientation between the two points (i.e. a baseline) using either:

  - Arbitrary azimuth of 000 deg.
  - Estimated azimuth (scaled from map or photo)
  - Magnetic azimuth (from transit or hand held compass)
  - Perform astronomic observation (Solar or Polaris)
  - Perform 8 to 15 minute GPS baseline observation, holding autonomous position at the primary end of the baseline
  - Gyroscope

- Perform topographic surveys relative to these two points. No grid or sea level corrections are applied to observed distances--a tangent plane grid is assumed.

a. No georeferenced control. Georeferenced control is rarely required for construction--an arbitrary system described above is totally adequate for all design, stakeout, and construction. In addition, an arbitrary grid system can be established in minutes--the baseline is quickly marked with stakes, hubs, rebar, or PK nails at each end. Topographic surveys using a total station or RTK can then be immediately conducted, starting at one end of the arbitrary baseline. If needed, supplemental control traverses can be run to set additional marked control points around the project site. Optionally, RTK radial control points can also be set relative to the baseline.

b. Georeferencing using autonomous GPS. If georeferenced control is required on this isolated project, then autonomous GPS positioning could be used to put approximate georeferencing on the primary control point. Georeferencing can be performed at any time. All data that was observed on the arbitrary grid system can later be translated (and rotated) to a planer georeferenced coordinate system. If only approximate georeferenced control is needed (± 20 ft), then an autonomous position from a hand-held GPS receiver is adequate (e.g., Garmin, PLGR), and noting on all survey records that any resultant coordinates are approximate. A few minute visual recording of the position is sufficient. Likewise, a quick autonomous GPS position on the other end of the baseline will establish a rough geodetic azimuth for the baseline--accurate to only ± 1 deg at best. If the receiver will convert Lat/Long to the local UTM zone, then the UTM coordinate system may be used to reference the project. A Lat/Long coordinate for the primary point on the baseline should not be shown to an accuracy greater than the nearest 0.1 second. A UTM coordinate should not be shown to better than the nearest meter.

c. Long-term static GPS observations. If a more precise georeferencing is required, then longer term static GPS observations must be made at the primary point on the baseline. Most GPS receivers can average long-term autonomous GPS positions-- over say 24 hours. This will derive a WGS 84 3D position accurate to approximately ± 2 meters. A higher accuracy (better than ± 1 meter) will be attained if geodetic quality GPS receivers are available. If two geodetic receivers are available, then a fixed solution can be achieved over the short baseline with only a few minutes of static observations.

d. Transformations. All databases and drawings must clearly note the approximate georeferencing of the project, the method by which it was performed, and the estimated accuracy of the primary reference point. Also clearly indicate that the project is referenced to WGS 84. The vertical datum is referenced either to the WGS 84 ellipsoid or to the approximate local geoid if a worldwide geoid model is available. Clearly note on drawings which vertical datum was held. If required, the project may also be referenced to a local OCONUS horizontal datum if the transformation parameters are known or are imbedded in the GPS receiver. Previous topographic observations on an arbitrary coordinate system may be transformed to the WGS 84/UTM grid using standard transformation routines found in most COGO software packages. These routines will also automatically apply grid and sea level corrections during the transformation--assuming these are significant.

6-13. Determining Required Map Scale and Contour Interval

General guidance for determining project-specific mapping requirements is contained in Table 6-1 at the end of this section and in Table 6-2 in the next section. Table 6-1 may be used to develop specifications for map scales, feature location tolerances, and contour intervals for typical engineering and construction projects. Functional activities are divided into military construction, civil works, real estate, hazardous waste, and emergency management. It is absolutely essential that surveying and mapping specifications originate from the functional requirements of the project, and that these requirements be realistic and economical. Specifying topographic map scales or accuracies in excess of those required for project planning, design, or construction results in increased costs to USACE, local sponsors, or installations, and may delay project completion. However, the recommended standards and accuracy tolerances shown in

Table 6-1 should be considered as general guidance for typical projects--variance from these norms is expected.

a. Mapping scope/limits. Mapping limits should be delineated so only areas critical to the project are covered by detailed ground topographic surveys. The areal extent of detailed, large-scale, site plan surveys should be kept to a minimum and confined to the actual building, utility corridor, or structure area. Outside critical construction perimeters, more economical smaller scale plans should be used, along with more relaxed feature location accuracies, larger contour intervals, etc.

b. Target scale and contour interval specifications. Map scale is the ratio of the distance measurement between two identifiable points on a map to the same physical points existing at ground scale. The errors in map plotting and scaling should exceed errors in measurements on the ground by a ratio of about 3 to 1. Stated in a different manner, a ratio can be established as a function of the plotter error divided by the allowable scale error. For example, if a digital plotter has an accuracy of 0.0008 ft (0.25 mm) and scaled map distances must be accurate to 0.5 ft, then $0.0008/0.5 \approx 1/600$; or the ratio becomes 1:600 or 1 inch = 50 feet. Table 6-1 provides recommended map scales and contour intervals for a variety of engineering applications. The selected target scale for a map or construction plan should be based on the detail necessary to portray the project site. Surveying and mapping costs will normally increase exponentially with larger mapping scales; therefore, specifying too large a site plan scale or too small a contour interval than needed to adequately depict the site can significantly increase project costs. Topographic elevation density or related contour intervals must be specified consistent with existing site gradients and the accuracy needed to define site layout, drainage, grading, etc., or perform quantity take offs. Photogrammetric mapping flight altitudes or ground topographic survey accuracy and density requirements are determined from the design map target scale and contour interval provided in the contract specifications.

c. Feature location tolerances. This requirement establishes the primary surveying effort necessary to delineate physical features on the ground. In most instances, a construction feature may need to be located to an accuracy well in excess of its plotted/scaled accuracy on a construction site plan; therefore, feature location tolerances should not be used to determine the required scale of a drawing or determine photogrammetric mapping requirements. In such instances, surveyed coordinates, internal CADD grid coordinates, or rigid relative dimensions are used. Table 6-1 indicates recommended positional tolerances (or precisions) of planimetric features. These feature tolerances are defined relative to adjacent points within the confines of a specific area, map sheet, or structure--not to the overall project or installation boundaries. Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc. Feature tolerances should be determined from the functional requirements of the project/structure (e.g., field construction/fabrication, field stakeout or layout, alignment, locationing, etc.). Few engineering, construction, or real estate projects require that relative accuracies be rigidly maintained beyond a 5,000-ft range, and usually only within the range of the detailed design drawing for a project/structure (or its equivalent CADD design file limit). For example, two catch basins 200 ft apart might need to be located to 0.1 ft relative to each other, but need only be known to ±100 ft relative to another catch basin 6 miles away. Likewise, relative accuracy tolerances are far less critical for small-scale GIS data elements. Actual construction alignment and grade stakeout will generally be performed to the 0.1 ft or 0.01 ft levels, depending on the type of construction.

d. Maintaining relative precision on a topographic survey. Ideally, all features located throughout a site area will have the same relative precision. In practice, the relative precision of the points located furthest from the project control points will tend to have more error than points located directly from control monuments. In order to maintain the required accuracy for a project, a primary project control net or loop is established to cover the entire project. Secondary project control loops or nets are constructed from the primary project network. This helps to ensure that the intended precision will not drop below the tolerance of the survey. In lieu of increasing control requirements, the target map scale may be reduced in outlying areas. This trade-off between survey control and scale either increases project costs or the scale is reduced below usable limits in some cases.

e. Optimum target scale. The requesting agency (or surveyor) should always use the smallest scale which will provide the necessary detail for a given project. This will provide economy and meet the project requirements. Once the smallest practical scale has been selected given the recommended options from Table 6-1, determine if any other future map uses are possible for this project which might need a larger scale. If no other uses are of practical value, then the optimum map scale has been determined.

f. Determining optimum contour interval. The contour interval is the constant elevation difference between two adjacent contour lines. The contour interval is chosen based on the map purpose, required vertical accuracy (if any was specified), the relief of the area of concern, and somewhat from the map target scale. Steep slopes (large relief) will cause the surveyor to increase the contour interval in order to make the map more legible. Flat areas will tend to decrease the interval to a limit which does not interfere with planimetric details located on the topographic map.

(1) As a general rule, the lower limit for the contour interval is 25 lines per inch for even the smallest map scales. The checklist to find the proper contour interval is:

- Intended purpose of the map.
- The desired accuracy of the depicted vertical information.
- Area relief (mountainous, hilly, rolling, flat, etc.).
- Cost of extra field work and possibility of plotting problems for selecting a smaller contour interval.
- Other practical uses for the intended map.

(2) Following the above checklist, contour interval ranges are recommended in Table 6-1 for the types of projects typically encountered in USACE. If a specific vertical tolerance has been specified as the purpose for the mapping project, then the contour interval may be determined as a direct proportion from Table 6-1 for the type of project site. Otherwise, the stated map accuracy of the vertical information will be in terms of the selected contour interval within the limits provided by Table 6-1.

(3) Any contour drawn on the map will be correct to a stated fraction of the selected contour interval. Because interpolation is used between spot elevations, the spot elevations themselves are required to be twice as precise as the contours generated by the spot elevations.

g. CADD level/layer descriptors. The use of CADD or GIS equipment allows planimetric features and topographic elevations to be readily separated onto various levels or layers and depicted at any scale. Problems may arise when scales are increased beyond their originally specified values, or when so-called "rubber sheeting" or "warping" is performed. It is therefore critical that these geospatial data layers, and related metadata files, contain descriptor information identifying the original source target scale and designed accuracy.

Table 6-1. RECOMMENDED ACCURACIES AND TOLERANCES: ENGINEERING, CONSTRUCTION, AND FACILITY MANAGEMENT PROJECTS

	Target	Feature Position Tolerance		Contour	Survey
	Map Scale	Horizontal	Vertical	Interval	Accuracy
Project or Activity	**SI/IP**	**SI/IP**	**SI/IP**	**SI/IP**	**Hor/Vert**
<u>DESIGN, CONSTRUCTION, OPERATION & MAINTENANCE OF MILITARY FACILITIES</u>					
Maintenance and Repair (M&R)/Renovation of Existing Installation Structures, Roadways, Utilities, Etc					
General Construction Site Plans & Specs:	1:500	100 mm	50 mm	250 mm	3rd-I
Feature & Topographic Detail Plans	40 ft/in	0.1-0.5 ft	0.1-0.3 ft	1 ft	3rd
Surface/subsurface Utility Detail Design Plans	1:500	100 mm	50 mm	N/A	3rd-I
Elec, Mech, Sewer, Storm, etc	40 ft/in	0.2-0.5 ft	0.1-0.2 ft		3rd
Field construction layout		0.1 ft	0.01-0.1 ft		
Building or Structure Design Drawings	1:500	25 mm	50 mm	250 mm	3rd-I
40 ft/in	0.05-0.2 ft	0.1-0.3 ft	1 ft	3rd	
Field construction layout		0.01 ft	0.01 ft		
Airfield Pavement Design Detail Drawings	1:500	25 mm	25 mm	250 mm	3rd-I
40 ft/in	0.05-0.1 ft	0.05-0.1 ft	0.5-1 ft	2nd	
Field construction layout		0.01 ft	0.01 ft		
Grading and Excavation Plans	1:500	250 mm	100 mm	500 mm	3rd-II
Roads, Drainage, Curb, Gutter etc.	30-100 ft/in	0.5-2 ft	0.2-1 ft	1-2 ft	3rd
Field construction layout		1 ft	0.1 ft		
Recreational Site Plans	1:1000	500 mm	100 mm	500 mm	3rd-II
Golf courses, athletic fields, etc.	100 ft/in	1-2 ft	0.2-2 ft	2-5 ft	3rd
Training Sites, Ranges, and Cantonment Area Plans	1:2500	500 mm	1000 mm	500 mm	3rd-II
	100-200 ft/in	1-5 ft	1-5 ft	2 ft	3rd
General Location Maps for Master Planning	1:5000	1000 mm	1000 mm	1000 mm	3rd-II
AM/FM and GIS Features	100-400 ft/in	2-10 ft	1-10 ft	2-10 ft	3rd
Installation boundaries, roads, buildings	100 ft/in				
Installation regional location	2,000 ft/in				
Installation vicinity map	1,000 ft/in				
Space Management Plans	1:250	50 mm	N/A	N/A	N/A
Interior Design/Layout	10-50 ft/in	0.05-1 ft			
As-Built Maps: Military Installation Surface/Subsurface Utilities (Fuel, Gas, Electricity, Communications, Cable, Storm Water, Sanitary, Water Supply, Treatment Facilities, Meters, etc.)	30 to 100 ft/in	100 mm	100 mm	250 mm	3rd-I
		0.2-1 ft	0.2 ft	1 ft	3rd
	1:1000 or 50-100 ft/in (Army)				
	1:500 or 50 ft/in (USAF)				

Table 6-1 (Contd). RECOMMENDED ACCURACIES AND TOLERANCES: ENGINEERING, CONSTRUCTION, AND FACILITY MANAGEMENT PROJECTS

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
Housing Management GIS (Family Housing, Schools, Boundaries, and Other Installation Community Services)	1:5000 100-400 ft/in	10000 mm 10-15 ft	N/A	N/A	4th 4th
Environmental Mapping and Assessment Drawings/Plans/GIS	1:5000 400 ft/in	10000 mm 10-50 ft	N/A	N/A	4th 4th
Emergency Services Maps/GIS Military Police, Crime/Accident Locations, Post Security Zoning, etc.	1:10000 400-2000 ft/in	25000 mm 50-100 ft	N/A	N/A	4th 4th
Cultural, Social, Historical Plans/GIS Archeological sites, habitat, endangered species, wildlife, wetlands	1:5000 400 ft/in	10000 mm 20-100 ft	N/A	N/A	4th 4th
Runway Approach and Transition Zones:	1:2500	2500 mm	2500 mm	1000 mm	3rd-II
General Plans/Section	100-200 ft/in	5-10 ft	2-5 ft	5 ft	3rd
Approach maps	1:5000 (H) 1:1000 (V)				
Approach detail	1:5000 (H) 1:250 (V)				
Runway end location	N/A	1 ft	0.2 ft	N/A	3rd
Airport Obstruction & NAVAID Surveys					
Airport Obstructions	N/A	20 ft	3 ft	N/A	3rd-II
NAVAID-visual	N/A	20 ft	N/A	N/A	3rd-II
NAVAID-electronic--radar	N/A	20 ft	100 ft	N/A	3rd-II
NAVAID-WAAS (absolute)	N/A	5 cm	10 cm	N/A	3rd
NAVAID-WAAS (relative)	N/A	1 cm	0.2 cm	N/A	2nd
Primary & Secondary Control Points	N/A	3 cm	4 cm	N/A	2nd
<u>DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE OF CIVIL TRANSPORTATION & WATER RESOURCE PROJECTS</u> Site Plans, Maps & Drawings for Design Studies, Reports, Memoranda, and Contract Plans and Specifications, Construction plans & payment					
General Planning and Feasibility Studies, Reconnaissance Reports	1:2500 100-400 ft/in	1000 mm 2-10 ft	500 mm 0.5-2 ft	1000 mm 2-10 ft	3rd-II 3rd
Flood Control and Multipurpose Project Planning, Floodplain Mapping, Water Quality Analysis, and Flood Control Studies	1:5000 400-1000 ft/in	10000 mm 20-100 ft	100 mm 0.2-2 ft	1000 mm 2-5 ft	3rd-II 3rd
Soil and Geological Classification Maps	1:5000	10000 mm	N/A	N/A	4th
400 ft/in	20-100 ft			4th	
Land Cover Classification Maps	1:5000	10000 mm	N/A	N/A	4th
400-1000 ft/in	50-200 ft			4th	

Table 6-1. (Contd). RECOMMENDED ACCURACIES AND TOLERANCES: ENGINEERING, CONSTRUCTION, AND FACILITY MANAGEMENT PROJECTS

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
Archeological or Structure Site Plans & Details					
(Including Non-topographic, Close Range,	1:10	5 mm	5 mm	100 mm	2nd-I/II
Photogrammetric Mapping)	0.5-10 ft/in	0.01-0.5 ft	0.01-0.5 ft	0.1-1 ft	2nd
Cultural and Economic Resource Mapping	1:10000	10000	N/A	N/A	4th
Historic Preservation Projects	1000 ft/in	50-100 ft			4th
Land Utilization GIS Classifications	1:5000	10000 mm	N/A	N/A	4th
Regulatory Permit Locations	400-1000 ft/in	50-100 ft			4th
Socio-Economic GIS Classifications	1:10000	20000 mm	N/A	N/A	4th
	1000 ft/in	100 ft			4th
Grading & Excavation Plans	1:1000	1000 mm	100 mm	1000 mm	3rd-I
	100 ft/in	0.5-2 ft	0.2-1 ft	1-5 ft	3rd
Flood Control Structure Clearing & Grading	1:5000	2500 mm	250 mm	500 mm	3rd-II
Plans (e.g., revetments)	100-400 ft/in	2-10 ft	0.5 ft	1-2 ft	3rd
Federal Emergency Management	1:5000	1000 mm	250 mm	1000 mm	3rd-I
Agency Flood Insurance Studies	400 ft/in	20 ft	0.5 ft	4 ft	3rd
Locks, Dams, & Control Structures	1:500	25 mm	10 mm	250 mm	2nd-II
Detail Design Drawings	20-50 ft/in	0.05-1 ft	0.01-0.5 ft	0.5-1 ft	2nd/3rd
Spillways & Concrete Channels	1:1000	100 mm	100 mm	1000 mm	2nd-II
Design Plans	50-100 ft/in	0.1-2 ft	0.2-2 ft	1-5 ft	3rd
Levees and Groins: New Construction or	1:1000	500 mm	250 mm	500 mm	3rd-II
Maintenance Design Drawings	100 ft/in	1-2 ft	0.5-1 ft	1-2 ft	3rd
Construction In-Place Volume Measurement	1:1000	500 mm	250 mm	N/A	3rd-II
Granular cut/fill, dredging, etc.	40-100 ft/in	0.5-2 ft	0.5-1 ft		3rd
Beach Renourishment/Hurricane	1:1000	1000 mm	250 mm	250 mm	3rd-II
Protection Project Plans	100-200 ft/in	2 ft	0.5 ft	1 ft	3rd

Table 6-1. (Contd). RECOMMENDED ACCURACIES AND TOLERANCES: ENGINEERING, CONSTRUCTION, AND FACILITY MANAGEMENT PROJECTS

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
Project Condition Survey Reports					
Base Mapping for Plotting Hydrographic	1:2500	10000 mm	250 mm	500 mm	N/A
Surveys: line maps or aerial plans	200-1000 ft/in	5-50 ft	0.5-1 ft	1-2 ft	N/A
Dredging & Marine Construction Surveys	1:1000	2000 mm	250 mm	250 mm	N/A
New Construction Plans--Rock	100 ft/in	6 ft	1 ft	1 ft	N/A
New Construction Plans--Soft material	100 ft/in	6 ft	2 ft	1 ft	N/A
Maintenance Dredging Drawings	1:2500	2000 mm	500 mm	500 mm	N/A
	200 ft/in	6 ft	1 or 2 ft	1 ft	N/A
Offshore Geotechnical Investigations	-	5000 mm	50 mm	N/A	N/A
Core Borings /Probings/etc.		5-15 ft	0.1-0.5 ft		4th
Structural Deformation Monitoring Studies/Surveys					
Reinforced Concrete Structures: Locks, Dams, Gates, Intake Structures, Tunnels, Penstocks, Spillways, Bridges	Large-scale vector movement diagrams or tabulations	10 mm 0.03 ft (long-term)	2 mm 0.01 ft	N/A	N/A N/A
Earth/Rock Fill Structures:Dams,Floodwalls, Levees, etc--slope/crest stability & alignment	(same as above)	30 mm 0.1 ft (long term)	15 mm 0.05 ft	N/A	N/A N/A
Crack/Joint & Deflection Measurements: piers/monoliths--precision micrometer	tabulations	0.2 mm 0.01 inch	N/A	N/A	N/A N/A

Table 6-1. (Concluded). RECOMMENDED ACCURACIES AND TOLERANCES: ENGINEERING, CONSTRUCTION, AND FACILITY MANAGEMENT PROJECTS

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Feature Position Tolerance Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
REAL ESTATE ACTIVITIES: ACQUISITION, DISPOSAL, MANAGEMENT, AUDIT					
Maps, Plans, & Drawings Associated with Military and Civil Projects					
Tract Maps, Individual, Detailing					
Installation or Reservation Boundaries,	1:1000	10 mm	100 mm	1000 mm	3rd-I/II
Lots, Parcels, Adjoining Parcels, and	1:1200 (Army)				3rd
Record Plats, Utilities, etc.	50-400 ft/in	0.05-2 ft	0.1-2 ft	1-5 ft	
Condemnation Exhibit Maps	1:1000	10 mm	100 mm	1000 mm	3rd-I/II
	50-400 ft/in	0.05-2 ft	0.1-2 ft	1-5 ft	3rd
Guide Taking Lines/Boundary Encroachment	1:500	50 mm	50 mm	250 mm	3rd-I/II
Maps: Fee and Easement Acquisition	20-100 ft/in	0.1-1 ft	0.1-1 ft	1 ft	3rd
General Location or Planning Maps	1:24000	10000 mm	5000 mm	2000 mm	N/A
	2000 ft/in	50-100 ft	5-10 ft	5-10 ft	4th
GIS or Land Information System (LIS) Mapping, General					
Land Utilization and Management, Forestry	1:5000	10000 mm	N/A	N/A	3rd
Management, Mineral Acquisition	200-1000 ft/in	50-100 ft			3rd
Easement Areas and Easement	1:1000	50 mm	50 mm	N/A	3rd
Delineation Lines	100 ft/in	0.1-0.5 ft	0.1-0.5 ft		3rd
HAZARDOUS, TOXIC, RADIOACTIVE WASTE (HTRW) SITE INVESTIGATION, MODELING, AND CLEANUP					
General Detailed Site Plans	1:500	100 mm	50 mm	100 mm	2nd-I/II
HTRW Sites, Asbestos, etc.	5-50 ft/in	0.2-1 ft	0.1-0.5 ft	0.5-1 ft	2nd/3rd
Subsurface Geotoxic Data Mapping	1:500	100 mm	500 mm	500 mm	3-II
and Modeling	20-100 ft/in	1-5 ft	1-2 ft	1-2 ft	3rd
Contaminated Ground Water	1:500	1000 mm	500 mm	500 mm	3rd-II
Plume Mapping/Modeling	20-100 ft/in	2-10 ft	1-5 ft	1-2 ft	3rd
General HTRW Site Plans &	1:2500	5000 mm	1000 mm	1000 mm	3rd-II
Reconnaissance Mapping	50-400 ft/in	2-20 ft	2-20 ft	2-5 ft	3rd

EXPLANATORY NOTES FOR COLUMNS IN TABLE 6-1:

1. Target map scale is that contained in CADD, GIS, and/or AM/FM layer, and/or to which ground topo or aerial photography accuracy specifications are developed. This scale may not always be compatible with the feature location/elevation tolerances required. In many instances, design or real property features are located to a far greater relative accuracy than that which can be scaled at the target (plot) scale, such as property corners, utility alignments, first floor or invert elevations, etc. Coordinates/elevations for such items are usually directly input into a CADD or AM/FM database.

2. The feature position or elevation tolerance of a planimetric feature is defined at the 95% confidence level. The positional accuracy is relative to two adjacent points within the confines of a structure or map sheet, not to the overall project or installation boundaries. Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc. The tolerances between the two points are determined from the end functional requirements of the project/structure (e.g., field construction/fabrication, field stakeout or layout, alignment, locationing, etc.).

3. Horizontal and vertical control survey accuracy refers to the procedural and closure specifications needed to obtain/maintain the relative accuracy tolerances needed between two functionally adjacent points on the map or structure, for design, stakeout, or construction. Usually 1:10,000 Third-Order (I) control procedures (horizontal and vertical) will provide sufficient accuracy for most engineering work, and in many instances of small-scale mapping or GIS rasters, Third-Order, Class II methods and Fourth-Order topo/construction control methods may be used. Base- or area-wide mapping control procedures shall be specified to meet functional accuracy tolerances within the limits of the structure, building, or utility distance involved for design or construction surveys. Higher order control surveys shall not be specified for area-wide mapping or GIS definition unless a definitive functional requirement exists (e.g., military operational targeting or some low gradient, flood control projects).

6-14. Recommended Guidelines for Army Installation Maps and Drawings

Table 6-2 below is extracted from the "*CADD/GIS Technology Center Guidelines for Installation Mapping and Geospatial Data*" (ERDC/ITL 1999b). It contains guidance on recommended scales for various types of military installation maps. The map class refers to the ASPRS standards (ASPRS 1989).

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

MAP AND GRAPHIC LAYERS *M=mandatory* *O=optional* *TBD=to be determined*		MAP SCALE 1"=xxxxft	MAP CLASS-ACCURACY	CONTOUR INTERVAL (feet)	DESCRIPTION AND FEATURES SHOWN
A- NATURAL AND CULTURAL RESOURCES A-1 AREAS OF CRITICAL CONCERN	M	1"=400ft 1:4,800	Class 1	5	Shows historic and archeological sites, areas of threatened and endangered species, primary habitat areas, flood plains, wetlands, coastal zones, lakes, rivers, water bodies, soils and soil boring locations, and similar information.
A- NATURAL AND CULTURAL RESOURCES A-2 MANAGEMENT AREAS	O	1"=400ft 1:4,800	Class 1	5	Shows surface/subsurface geology, paleontology, topography, hydrology and surface drainage, vegetation areas, forests, commercial timber areas, agricultural outleasing areas, fish and wildlife areas, prime soils, grounds maintenance areas, outdoor recreation areas, pest management areas, and similar information.

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

B- ENVIRONMENTAL QUALITY B-1 ENVIRONMENTAL REGULATORY AREAS	M	1"=400ft 1:4,800	Class 1	5	Shows hazardous waste generation points, hazardous waste storage facilities, solid waste disposal and recycling points, fuel tanks, Resource Conservation and Recovery Act sites, installation restoration program sites/areas, and similar information.
B- ENVIRONMENTAL QUALITY B-2 ENVIRONMENTAL EMISSIONS AREAS	O	1"=400ft 1:4,800	Class 1	5	Shows sources of air emissions, wastewater Non-point Pollution Discharge Elimination System (NPDES) point source discharges, storm water non-point discharges, drinking water supply, electromagnetic radiation sources, sources of radon emissions and similar information.
C-INSTALLATION LAYOUT AND VICINITY C-1 INSTALLATION LAYOUT	M	1"=100ft 1:1,200	Class 1	2	Shows the installation boundary; buildings (facility identification numbers and type: permanent, semi-permanent, temporary); structures; roads and parking areas; walkways and trails; railroads; fences; recreation areas; cemeteries; training ranges; contours; water areas; coordinate grid; embankments; below/above ground tanks; embankments; spot elevations and survey control; neighboring land use (outside installation boundary); historic buildings and places, archeological sites and similar information.
C-INSTALLATION LAYOUT AND VICINITY C-2 OFF-INSTALLATION SITES	M	1"=400ft 1:4,800	Class 1	5	Shows the same information as the installation layout map, but this map is prepared for those facilities that are outside the installation's primary boundary.
C-INSTALLATION LAYOUT AND VICINITY C-3 INSTALLATION REGIONAL LOCATION	O	1"=2,000ft 1:24,000	NA	20	Shows information of interest to regional planning and major transportation systems, cities, towns, political jurisdictions, DoD installation boundaries, aeronautical data, woodlands, recreation areas, towers, significant physical characteristics of the region and other similar information.
C-INSTALLATION LAYOUT AND VICINITY C-4 INSTALLATION VICINITY	O	1"=1000ft 1:12,000	Class 1	10	Shows the installation boundary, airfield and operations areas, major roads, proposed roads and highways, railroads, bombing and test ranges, vertical obstructions, topography, recreation areas, waterways and bodies, towers and similar information.

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

C-INSTALLATION LAYOUT AND VICINITY C-5 AERIAL PHOTOGRAPHIC COVERAGE AND CONTROL STATIONS	O		NA	NA	Prepared as an index of the aerial photographic coverage for the installation, shows the center point of individual photographs as well as the location of survey control stations and control points used for the aerial photography.
C-INSTALLATION LAYOUT AND VICINITY C-6 INSTALLATION BOUNDARY	M	Legal Records	Class 1	1	Shows the land area comprising the installation boundary including survey monuments.
D- LAND USE D-1 INSTALLATION LAND USE D-1.1 FUTURE LAND USE	M	1"=400ft 1:4,800	Class 1	5	Shows installation land use including airfields; maintenance and repair areas; manufacturing industrial areas; supply/ storage areas; administration areas; training and ranges areas; troop and family housing; community facilities (commercial and service); medical facilities; outdoor recreation; open spaces; and similar information
D- LAND USE D-2 OFF SITE LAND USE D-2.1 FUTURE OFF SITE LAND USE	O	1"=400ft 1:4,800	Class 1	5	Shows off-site land use including airfields; maintenance and repair areas; manufacturing industrial areas; supply/ storage areas; administration areas; training and ranges areas; troop and family housing; community facilities (commercial and service); medical facilities; outdoor recreation; open spaces; and similar information
D- LAND USE D-3 REAL ESTATE	O	1"=400ft 1:4,800	Class 1	2	Shows the land area comprising the installation including parcel information on fee title, lease, license, permit and easement areas inclusive of tract, acreage, data of acquisition, lease period and similar information.
D- LAND USE D-4 EXPLOSIVE SAFETY QUANTITY-DISTANCE CLEARANCE ZONES (QD-ARCS)	M	1"=400ft 1:4,800	Class 1	5	Same as installation layout map, but includes the distance clearance zones for explosives.
D- LAND USE D-5 HAZARD ANALYSIS CONSTRAINTS	M	1"=400ft 1:4,800	Class 1	5	Same as installation layout map, but includes areas of catastrophic potential to include flooding, subsidence, avalanche, erosion, earthquake, tsunami, snowfall, windstorm, volcanic ash and similar information.
D- LAND USE D-6 COMPOSITE CONSTRAINTS	M	1"=400ft 1:4,800	Class 1	5	Same as installation layout map, but emphasizes areas of catastrophic potential from natural occurrences e.g., flooding, subsidence, avalanche, earthquake, tsunami and technological occurrences, accident potential zones, hazardous noise areas, noise contours, environmental

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

					management areas and other similar information.
D- LAND USE D-7 AREA DEVELOPMENT	O	1"=100ft 1:1,200	Class 1	2	Same as installation layout map, but includes information on the planned development of areas within the installation.
E-AIRFIELD OPERATIONS E-1 ON-BASE OBSTRUCTIONS TO AIRFIELD CRITERIA	M	1"=1,000ft 1:12,000	Class 1	5	Same as airport pavement map and includes information on any obstructions to navigation and ground movement of aircraft within the installation boundary.
E-AIRFIELD OPERATIONS E-2 APPROACH/DEPARTURE ZONE OBSTRUCTIONS (to 10,000 feet)	M	1"=800ft	Class 1	5	Shows obstructions within the glide angle approach zone and other similar information within the distance specified.
E-AIRFIELD OPERATIONS E-3 APPROACH/DEPARTURE ZONE OBSTRUCTIONS (from 10,000 feet to 10 miles)	M	1"=2,000ft 1:24,000	Class 1	10	Shows obstructions within the glide angle approach zone and other similar information within the distance specified.
E-AIRFIELD OPERATIONS E-4 AIRSPACE OBSTRUCTION-VICINITY	M	1"=1,000ft 1:12,000	Class 1	10	Shows obstructions within the vicinity of the airfield, but not those already shown on approach/departure zone maps, topography, cities, towns, other obstructions, water courses and water bodies and similar information.
E-AIRFIELD OPERATIONS E-5 TERMINAL ENROUTE PROCEDURES (TERPS) AUTOMATION	M	TBD	TBD	TBD	Shows all NAVAIDS with latitude and longitude.
E-AIRFIELD OPERATIONS E-6 AIRFIELD/AIRSPACE CLEARANCES	O	1"=100ft 1:1,200	Class 1	2	Shows airfield waivers, clear zones, primary surface, transitional surface (7:1), approach and departure surface (50:1) approach and taxiway clearances, wing tip clearances, turning radii, and other similar information necessary for aircraft movement on the ground.
E-AIRFIELD OPERATIONS E-7 AIRFIELD PAVEMENT	O	1"=400ft 1:4,800	Class 1	5	Shows runways, taxiways, aprons, warm-up pads, hardstands, helipads, stabilized shoulders, overruns and similar information.
E-AIRFIELD OPERATIONS E-8 AIRFIELD PAVEMENT DETAILS	O	1"=100ft 1:1,200	Class 1	2	Shows runways, taxiways, aprons, warm-up pads, hardstands, helipads, stabilized shoulders, overruns and similar information, but includes cross sections and elevation profiles.
E-AIRFIELD OPERATIONS E-9 AIRCRAFT PARKING E-9.1 PROPOSED AIRCRAFT PARKING	O	1"=100ft 1:1,200	Class 1	2	Shows the parking plan for aircraft including alert hangars, refueling outlets, blast fences, aircraft orientation, control tower, fire station, cargo holding pads, maintenance

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

					docks, maintenance lights, aircraft revetments and similar information.
E-AIRFIELD OPERATIONS E-10 AIRFIELD LIGHTING SYSTEMS	O	1"=100ft 1:1,200	Class 1	2	Shows the major components of airfield lighting system including runway, taxiway, end reference lights, location size and type of underground ducts, obstruction lights, stand-by generator equipment and similar information.
F- Reserved					
G-UTILITY SYSTEMS G-1 WATER SUPPLY SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the water supply system.
G-UTILITY SYSTEMS G-2 SANITARY SEWERAGE SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the sanitary sewerage system.
G-UTILITY SYSTEMS G-3 STORM DRAINAGE SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the storm drainage system.
G-UTILITY SYSTEMS G-4 ELECTRICAL DISTRIBUTION SYSTEM (STREET AND AIRFIELD)	M	1"=50ft 1:600	Class 1	2	Shows all significant components of the electrical distribution and exterior lighting systems.
G-UTILITY SYSTEMS G-5 CENTRAL HEATING/COOLING SYSTEMS	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the central heating/cooling systems.
G-UTILITY SYSTEMS G-6 NATURAL GAS DISTRIBUTION SYSTEM	M	1"=50ft 1:600	Class 1	2	Shows all significant components of the natural gas distribution system.
G-UTILITY SYSTEMS G-7 LIQUID FUEL SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the liquid fuel system.
G-UTILITY SYSTEMS G-8 CATHODIC PROTECTION SYSTEM	O	1"=100ft 1:1,200	Class 1	2	Shows all significant components of the cathodic protection system for all underground utility systems and structures subject to electrochemical corrosion.
G-UTILITY SYSTEMS G-9 CATHODIC PROTECTION SYSTEM DETAILS	O	1"=50ft 1:600	Class 1	2	Shows all significant components of the cathodic protection system including details of other utilities in proximity to ground beds for all underground utility systems.
G-UTILITY SYSTEMS G-10 INDUSTRIAL WASTE AND DRAIN SYSTEM	O	1"=50ft 1:600	Class 1	2	Prepared when these systems are of such a complexity or nature it requires the production of a separate map to portray their characteristics.
G-UTILITY SYSTEMS G-11 COMPOSITE UTILITY SYSTEM	M	1"=100ft 1:1,200	Class 1	2	Shows the water, sanitary sewer, storm drainage, electrical, central heating/cooling, gas compressed air, industrial waste and other utility systems combined on a single map.

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

G-UTILITY SYSTEMS G-11.1 CENTRAL AIRCRAFT SUPPORT SYSTEMS	O	1"=50ft 1:600	Class 1	2	Shows all the utilities systems that serve the airfield apron and related servicing of aircraft.
G-UTILITY SYSTEMS G-12 FIRE PROTECTION SYSTEMS AND UTILITIES	M	1"=400ft 1:4,800	Class 1	5	Shows fire hydrants, water deluge systems, safety buffer distances, vehicle maneuverability areas, and similar information related to fire protection or safety.
G-UTILITY SYSTEMS G-13 OTHER UTILITY SYSTEMS	O	1"=100ft 1:1,200	Class 1	2	Show utilities not displayed on other maps.
H-COMMUNICATION AND NAVAID SYSTEMS H-1 INSTALLATION-WIDE COMMUNICATIONS AND COMPUTER SYSTEMS	M	1"=400ft 1:4,800	Class 1	5	Uses the installation layout map as a base to show installation-wide communications systems.
H-COMMUNICATION AND NAVAID SYSTEMS H-2 NAVAID SYSTEMS	M	1"=400ft 1:4,800	Class 1	5	Shows NAVAID components such as radio transmitters, radio relay facilities, high and ultra high frequency direction finders, radio beacon shelters, GCA units, RAPCON units, PAR structures, TACAN buildings and facilities and similar information.
I-TRANSPORTATION SYSTEM I-1 COMMUNITY NETWORK - ACCESS TO BASE	M	1"=400ft 1:4,800	Class 1	10	Shows all major arterial, collector streets that have direct relationship to the installation and local streets providing access to the installation.
I-TRANSPORTATION SYSTEM I-2 ON-BASE NETWORK	M	1"=400ft 1:4,800	Class 1	2	Shows the transportation network including parking areas, sidewalks, bike/hike/jogging trails on the installation.
I-TRANSPORTATION SYSTEM I-2.1 FUTURE ON-BASE NETWORK	O	1"=400ft 1:4,800	Class 1	2	Shows the planned transportation network including parking areas, sidewalks, bike/hike/jogging trails on the installation.
J-ENERGY SYSTEMS	O	1"=100ft 1:1,200	Class 1	2	Shows data related to the installation's energy planning systems.
K-ARCHITECTURAL COMPATIBILITY	O	1"=400ft 1:4,800	Class 1	2	Shows the installation's architectural compatibility zones and architectural districts.
L-INSTALLATION LANDSCAPE DEVELOPMENT AREA	O	1"=400ft 1:4,800	Class 1	2	Shows the installation's landscape areas and planned flora.
M-FUTURE DEVELOPMENT M-1 CURRENT	M	1"=400ft 1:4,800	Class 1	5	Shows the current installation layout; e.g. streets, parking lots, buildings, utilities etc, to include those facilities presently under development.
M-FUTURE DEVELOPMENT M-2 FUTURE DEVELOPMENT SHORT-TERM (1-5 YEARS)	M	1"=400ft 1:4,800	Class 1	5	Shows planned development on the installation including streets and parking lots, buildings, utilities and

Table 6-2
Recommended Installation Mapping Guidelines

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

					similar information.
M-FUTURE DEVELOPMENT M-2 FUTURE DEVELOPMENT SHORT-TERM (> 5 YEARS)	M	1"=400ft 1:4,800	Class 1	5	Shows the facilities that will be developed beyond a five-year time frame on the installation including streets and parking lots, buildings, utilities and similar information.
O-FORCE PROTECTION 0-1 SURGE CAPABILITY (BEDDOWN AND SUPPORT)	O	1"=400ft 1:4,800	Class 1	5	Show areas that can be suited for temporary billeting of troops in the case of surge requirements.
O-FORCE PROTECTION 0-2 PHYSICAL SECURITY	M	1"=400ft 1:4,800	Class 1	5	Shows security fences, proposed and existing access points, sensor devices, location of security police units, fire stations and other similar information.
O-FORCE PROTECTION 0-3 DISASTER PREPAREDNESS CRASH GRID	M	1"=400ft 1:4,800	Class 1	5	Shows all buildings and building numbers with hospitals and fallout shelters, protection factors and similar information.
O-FORCE PROTECTION 0-4 INSTALLATION SURVIVABILITY	O	1"=400ft 1:4,800	Class 1	5	Prepared for installations to show operational contingencies.
P-PORTS AND HARBORS	O	1"=100ft 1:1,200	Class 1	2	Shows berths, breakwater, channel, cable and pipeline areas, hazard areas, dry dock, navigation aides, jetties, wrecks, bouys, piers, quays, reefs, safety fairway, wharf, and other similar information.
R- TRAINING COMPLEX R-1 RANGE AREA	0	1"=400ft 1:4,800	Class 1	5	Shows surface danger zones, target areas, impact areas, dudded areas, bomb circles, firing points, firing fans and lanes, range control points, and other similar information.
R- TRAINING COMPLEX R-2 TRAINING AREA	0	1"=400ft 1:4,800	Class 1	5	Shows landing zones, drop zones, bivouac areas, training sites, foot traffic areas, perimeter defense, obstacle course areas, drill fields, marching areas and other similar information.

6-15. Topographic Survey Equipment Selection and Planning Guidance

This section discusses the selection of topographic survey instruments and methods for a given project. There is no set formula for deciding on a particular instrument (transit-tape, transit-stadia, plane table, total station, RTK, Laser) or survey densification technique (cross-sections, grid matrix, random). This is because of the large number of variables involved that will impact the use of one instrument or method versus another. These variables also have a major impact on productivity and cost. Some of these variables are discussed in the following paragraphs.

- Size of project. A simple stakeout of a baseball field can be accomplished easily with a transit and 100/300 ft steel tape--a total station or RTK would be overkill for such a project. On the other hand, a detailed site plan survey of a multi-acre planned commissary site would require a more productive instrument, such as a total station or RTK.

- Complexity of project. If only ground elevation shots are required at a site, survey data hand recorded in a field book would suffice. A project with many different feature levels, and with attribute options for each feature, would be more effectively surveyed using an electronic data collector--with a "field-finish" option if available.

- Project location. A remote or hazardous site location may dictate the type of equipment used. Lengthy mob/demob travel times will significantly increase costs, as will sites that can only be reached on foot.

- Project time constraints. A quick delivery suspense date may require use of electronic "field-finish" survey techniques; perhaps even laser techniques if a complex structure is involved. Specified overtime may increase costs.

- Project cost constraints. Always a driving factor--may preclude use of terrestrial laser technique. Or the cost may dictate a one-man crew with a robotic total station.

- User/requestor preferences. The originating office may have a preference for a particular survey method, including detailed data acquisition specifications. This user preference may or may not be the most economical method.

- Project accuracy specifications. The requested accuracy requirements from the using office may be unrealistically tight, and may preclude using a particular method even though it might have sufficed for the work. For example, if 0.2 ft horizontal accuracy is specified for all feature locations, a transit-tape or transit-stadia survey method is ruled out. Over specifying accuracy is probably the biggest cost driver on a project.

- Tree coverage. Dense canopy cover will eliminate use of RTK methods. If canopy is low (less than 20 to 25 ft) an expandable prism pole may be used to reach over the canopy.

- Ground vegetation. Heavy ground vegetation typically precludes use of laser/LIDAR survey methods. If vegetation is thick, line clearing may be needed to obtain direct total station shots. RTK may be more productive in such areas.

- Above ground and underground utility detail required. If complex utility infrastructure needs to be mapped, a total station may be the most practical method. If detailed attribute sketches are required, a pen tablet type notebook may be preferable to a field book. Utility work can represent 50% or more of the survey cost.

- Site elevation relief. A site with high relief will make obtaining ground shots difficult, particularly if climbing or rappelling is required to access shot points. This might occur on highly complex mechanical facilities where it is difficult to occupy overhead HVAC lines with a reflector or GPS antenna. Site relief will also be a major factor in productivity estimates, particularly if dense vegetation is also involved. A reflectorless total station may be the best solution in these areas.

- Ground topographic shot density requirements. Usually the terrain gradient dictates the shot density required to model the ground. In some cases, the requesting agency may dictate a certain "post spacing," which may or may not make any sense given the ground relief. Determining the optimum shot spacing density has traditionally been left to the experienced field surveyor. This was the case when a plane table was the method of choice for developing site plans for design. The field Party Chief based the amount of ground relief detail he collected on the project design requirement, and verified coverage before leaving the field. This is still true of electronic data collectors--the Party Chief must confirm that the shot density is sufficient to generate a DTM that is adequate for the project purpose. The critical component is the project purpose--dense topographic data is not needed on a site where little, if any, excavation will be performed. Thus, it is critical that the Party Chief have knowledge of the planned/proposed design and construction effort, and base the collection density on that criteria.

- Instrument availability. Not all survey organizations have a full complement of instrumentation technologies available. A smaller firm may have only an electronic total station but has not invested in an expensive RTK system.

- Instrument data collection productivity. Data collection productivity is highly dependent on the type of feature data being collected and the instrument used to collect the data. Collection rates can be as long as a few minutes per feature in the case of a transit or plane table where slope distances must be hand reduced and recorded or plotted. Transit and plane table surveys typically collected between 100 and 200 points in a day. The other extreme is a terrestrial laser that can collect thousands of points/sec (without any attribution). Data collection rates for a total station or RTK system are roughly the same--both use a similar data collection system with nearly identical COGO options. Continuous ground shot points can be collected every few seconds--as long as it takes the rod/prism-person to move between points. (Some systems have a "continuous" tracking mode which will update the points every second or so). When different features are shot, the descriptor codes (and perhaps attributes) must be entered into the data collector. If a two-digit descriptor code is used, shots can be completed in a few seconds. Additional time will be required depending on the amount of attribution. A feature requiring a detailed field sketch may require a few minutes to complete. Thus, depending on the nature of the project and features, a total station or RTK system can collect anywhere from 300 to 2,000 points in a day.

- Data collector requirements. The requesting agency may dictate a particular data collector format be used, in addition to mandating use of a data collector itself (no field book option).

- Final product deliverable format. The requesting agency usually mandates a specific CADD or GIS deliverable format. This may impact the field data collection method.

- Crew or instrument operator experience. Plane table surveys are probably not a survey option any more given few experienced plane table operators are still employed. Most engineers and surveyors can operate a transit or level, read stadia, or use a steel tape. Thus, these methods would be effective for a small topographic survey or stake out if a total station crew is unavailable. ("Small" means less than one day).

The following tables provide rough guidance for determining the density of shots needed to delineate planimetric features and terrain topography.

Table 6-3. Nominal Data Density Shot Intervals for Various Planimetric Features

Planimetric Feature	Recommended Spacing of Shots along Feature Target Scale 1" = 30 ft	 1" = 50 ft	 1" = 100 ft
Linear features (curbs, roads, buildings, utilities)	30 ft	50 ft	100 ft
Irregular features (breaklines, contours, shoreline, walkways, etc.)	10 ft	15 ft	30 ft
Rectangular or circular utility features (junction boxes, manholes, catch basins, etc.) detail corners or perimeter limits if objects maximum dimension is larger than	5 ft	10 ft	20 ft
Circular curves (roads, curbs, etc.) Delineate curve with	3 points	3 points	3 points

Table 6-4. Nominal Post Spacing Intervals and Density (Shots per Acre) for Topographic Ground Detail

Terrain Gradient (% slope)	Recommended Post Spacing (Density) of Shots on Ground Contour Interval 1 ft	 2 ft	 5 ft
< 1 %	50 ft (25 pts/acre)	100 ft (10 pts/acre)	250 ft (4 pts/acre)
< 5 %	10 ft (440 pts/acre)	20 ft (120 pts/acre)	50 ft (25 pts/acre)
<10 %	5 ft (1,600 pts/acre)	10 ft (440 pts/acre)	25 ft (80 pts/acre)
> 10 %	[as required to delineate feature]		

Given the large number of variables listed above, estimating topographic survey productivity is difficult--especially if underground utility location is required. Past experience on similar sites is probably the most reliable estimate. Use of estimating ratios, such as "acres/day" and "$/acre" may be of some value; however, these ratios are only representative to a particular site. For example, the 30-acre site in Appendix G (*Topographic Survey of Hannibal Lock & Dam, Proposed Nationwide DGPS Antenna Site (Pittsburgh District)*) was surveyed at a cost of $425/acre at a productivity rate of 5 acres/day. This is a relatively flat, clear site (mowed grass with isolated trees), with few utilities. If this site had been heavily vegetated and treed, requiring extensive line clearing, the cost/acre could easily have doubled or tripled.

Table 6-5. Matrix of Estimated Productivity Rates (Acres/Day) for Various Site Conditions

Nominal Site Condition	Estimated rate (acres/day)
Topography	
Flat, clear ground (no vegetation)	5 to 10 acres/day
Flat, isolated trees	4 to 8 acres/day
Flat, heavily treed (traverse reqd)	3 to 6 acres/day
Flat, heavily treed & vegetated (traverse & line cutting)	1 to 2 acres/day
Rolling terrain, clear ground (no vegetation)	3 to 5 acres/day
Rolling terrain, isolated trees	1 to 2 acres/day
Rolling terrain, heavily treed	0.5 to 1 acres/day
Rolling terrain, heavily treed & vegetated	0.2 to 0.5 acres/day
Planimetry	
Rural, isolated buildings & roads	10 acres/day
Urban, subdivision	1 acre/day
Installation, military	2 acres/day
Lock and Dam area	2 acres/day